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An Assessment of the Oil Resource Base of the United States

Oil Resources Panel

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October 1992

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EXECUTIVE SUMMARY

A select panel of oil resource analysts, convened on August 31 and September 1, 1992 by the Bureau of Economic Geology, The University of Texas at Austin, and the National Institute for Petroleum and Energy Research (NIPER) at the request of the U.S. Department of Energy, concludes that the remaining, recoverable volume of crude oil in the United States ranges from 99 to 204 billion barrels, inclusive of 25 billion barrels of oil carried as proved reserves by the Energy Information Administration (EIA) at the end of 1991 (table A). The range in estimates reflects different assumptions of price and technology (including the geological ability to apply technology). The lower estimate assumes a stable oil price of $20 per barrel (1992 dollars) with existing technology. The higher estimate assumes a price of $27 per barrel (1992 dollars) but with advanced technology. The range in estimates of the remaining resource base recoverable under the given assumptions is equivalent to 35 to 75 years of continued U.S. crude oil production at the current annual rate of 2.7 billion barrels.

In the Oil Resources Panel's estimation of recoverable resources, both price and technology are significant and they are almost equivalent in their impact (fig. A). The average estimate for recoverable volumes (total undiscovered resources and reserve growth) at both price levels was approximately two-thirds greater with the assumption of advanced technology than with existing technology (table B). The impact of technology and its application was judged to boost recoverable discovery volumes by about 45 percent, as panelists assumed that the 30-year history of improving discovery efficiencies, led by geophysical detection

Table A. U.S. oil resource base (billion barrels, 1992 constant dollars).

	Existing technology ($20/bbl)	Advanced technology ($20/bbl)	Existing technology ($27/bbl)	Advanced technology ($27/bbl)
Reserve growth in existing fields	31	55	43	89
Undiscovered resources	43	62	62	90
Proved reserves at yearend 1991	25	25	25	25
Total resources	**99**	**142**	**130**	**204**
Cumulative production at yearend 1991	164	164	164	164
Ultimate recovery	**263**	**306**	**294**	**368**

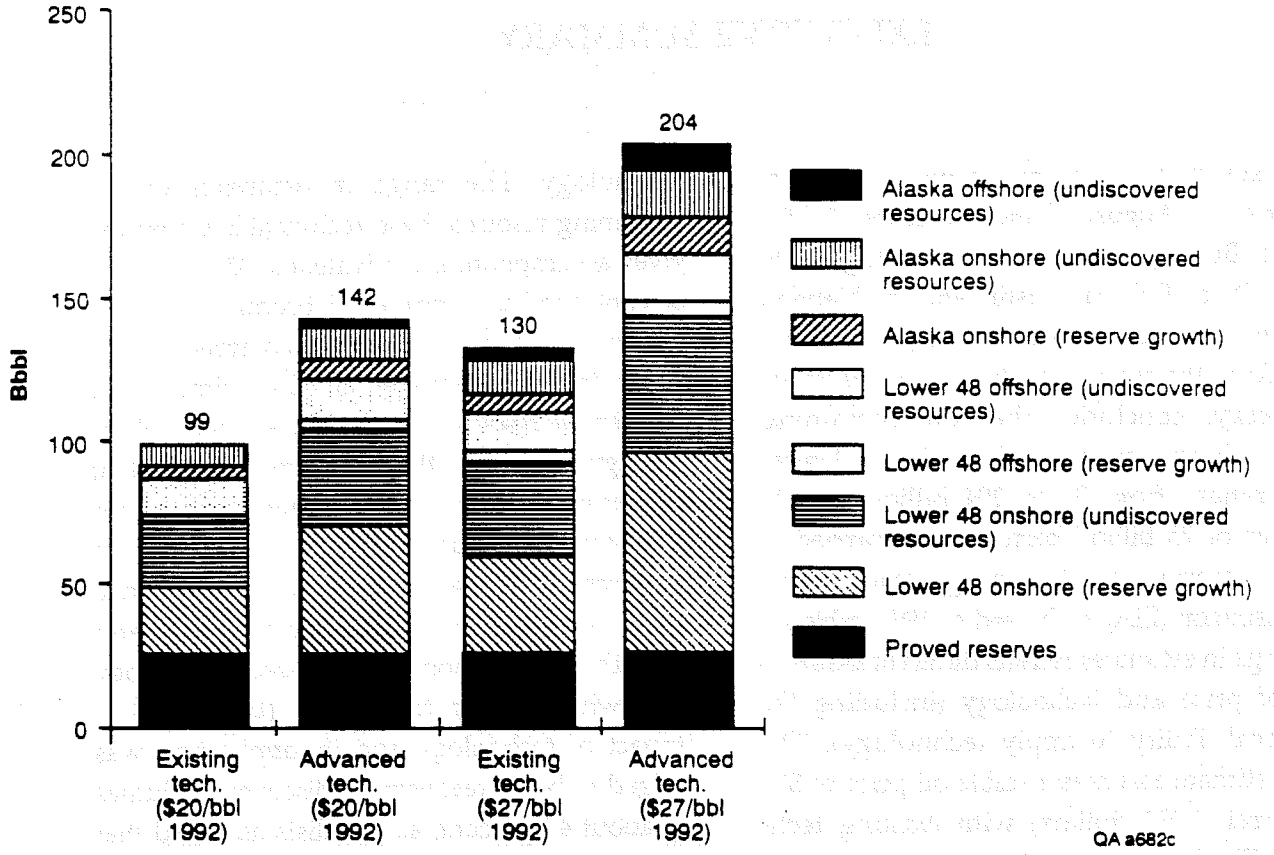

Figure A. Reserve growth, undiscovered resources, and proved reserves.

technology and new exploration concepts, would continue. Because the collective judgment of the Panel was that many of the discovery technologies will be applied at the reservoir level, advanced technology resulted in approximately an 80- to 100-percent increase in the reserve growth estimates. Recoverable volumes from reserve growth were judged to be higher at $20 per barrel with advanced technology than at $27 per barrel with existing technology. Significantly, this shows that the use of advanced technology can have at least as much impact as price increases in terms of increasing resource recovery.

Future potential was estimated by the Panel to be nearly equally divided between reserve growth from existing, already discovered fields and new fields yet to be discovered. About two-thirds of the total remaining potential is onshore in the lower 48 states, largely due to reserve growth from existing fields. About one-third of the total remaining potential is in offshore lower 48 and onshore and offshore Alaska. Whereas the frontier

Table B. Summary of estimates by the Oil Resources Panel (billion barrels).

	Existing technology ($20/bbl)	Advanced technology ($20/bbl)	Existing technology ($27/bbl)	Advanced technology ($27/bbl)
Lower 48 onshore				
Reserve growth	24	45	33	70
Undiscovered resources	24	34	33	48
Subtotal	48	79	66	118
Lower 48 offshore				
Reserve growth	2	3	3	6
Undiscovered resources	11	14	13	17
Subtotal	13	17	16	23
Alaska onshore				
Reserve growth	5	7	7	13
Undiscovered resources	8	12	12	17
Subtotal	13	19	19	30
Alaska offshore				
Undiscovered resources	—	2	4	8
Total undiscovered resources	43	62	62	90
Total reserve growth	31	55	43	89
Total undiscovered resources and reserve growth	74	117	105	179

areas—Alaska and the lower 48 offshore—hold about one-third of the judged future potential, these areas hold nearly half of the future discovery potential and most of the potential for giant field discovery (table B).

As expected with a diverse panel, individual estimates varied. There was a narrow distribution of the estimates of reserve growth and a wide distribution of the estimates of undiscovered resources. The average estimates of the Oil Resources Panel were higher than the average of several previous estimates made in the past 5 years for overall future potential at the lower price level, and they were approximately the same at the higher price level (table C). In the case of reserve growth potential, the Panel's average estimates were, with one exception, lower than previous estimates. The Panel's estimates of future discovery potential with an oil price assumption of $20 per barrel were about

Table C. Comparison of average estimates of the Oil Resources Panel with average of other recent estimates (billion barrels, constant dollars).

	Existing technology (lower price)	Advanced technology (lower price)	Existing technology (higher price)	Advanced technology (higher price)
Undiscovered resources	43 (31)	62 (38)	62 (52)	90 (61)
Reserve growth	31 (24)	55 (62)	43 (53)	89 (121)
Total resources	74 (55)	117 (100)	105 (105)	179 (182)

Note: The average of other recent estimates is in parentheses.

40 to 45 percent higher than previous estimates for the frontier areas of the U.S. offshore and Alaska, but 40 to 90 percent higher for the onshore lower 48 states.

Although the Panel's estimate of future oil resources recoverable at moderate prices is substantial, only sensitivity to price and technology was considered. Wellhead prices considered were assumed to be stable, though no guarantee against future price volatility exists. The advanced technology scenarios presuppose that research and development will be done to realize that technology. This may not happen, as there has been a downsizing of research and development efforts in the private sector in recent years. Physical access to the remaining resource base was not evaluated, but current policy seriously limits the potential of the U.S. offshore and Alaska—areas of significant potential for large-field discovery. The rate of abandonment of existing fields is also a concern. To the extent that fields are abandoned before projected reserve growth is realized, resource potential will not be realized at the prices here assumed. Future costs were assumed to be held down or reduced through advanced technology. However, regulatory constraints and the substantial costs of environmental regulations as well as the impact of future, long-term environmental liabilities were not considered explicitly, and they could also seriously limit the potential for recovery of the oil resources.

Table D. Members of the Oil Resources Panel

Jerry Brashear
Senior Vice President
ICF Resources Incorporated

Thomas E. Burchfield
Director of Energy Production Research
National Institute for Petroleum
and Energy Research

Robert D. Gunn
President
Gunn Oil Company

Donald A. Juckett
Director of Oil and Gas
Exploration and Production
Office of Fossil Energy
U.S. Department of Energy

Gary Lore
Regional Supervisor
Resource Evaluation
Minerals Management Service
U.S. Department of the Interior

Charles J. Mankin
State Geologist and Director
Oklahoma Geological Survey

Richard Mast
Research Geologist
U.S. Geological Survey
U.S. Department of the Interior

Riley Needham
Phillips Fellow Emeritus
Phillips Petroleum Company

Richard Nehring
President
NRG Associates

Steven E. Plotkin
Senior Associate
Office of Technology Assessment
Congress of the United States

Arlie M. Skov
Executive Consultant
BP Exploration, Inc.

Ray Thomasson
President
Thomasson Partner Associates

Noel Tyler
Associate Director
Bureau of Economic Geology
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John Wood
Director
Dallas Field Office
U.S. Department of Energy

Dalton Woods
President
Dal Woods Corporation

Thomas J. Woods
Executive Energy Analyst
Gas Research Institute

William L. Fisher
Director
Bureau of Economic Geology
The University of Texas at Austin
Panel Chair

INTRODUCTION

This assessment of United States oil resources is based on a review and analysis of recent major studies of the recoverable portion of the resource base and the qualitative judgment of a panel of experts from Federal departments and agencies, State geological surveys, and industry. The total recoverable portion of the U.S. oil resource base is assessed, as of August 1992, and estimates are provided for undiscovered resources and reserve growth. Four scenarios are developed using two price levels ($20 and $27 per barrel) and two levels of technology (existing and advanced).

Approach to the Study

The approach to this study was to review and compare recent estimates of the U.S. oil resource base made in major resource assessments undertaken by the U.S. Geological Survey and the Minerals Management Service of the U.S. Department of the Interior, the Energy Information Administration of the U.S. Department of Energy, the Geoscience Institute for Oil and Gas Recovery Research, the Governor's Energy Council of the State of Texas, the American Association of Petroleum Geologists, the National Research Council, the State of Alaska, and the U.S. Department of Energy (apps. 1–3). Estimates and per-spectives were presented to the Oil Resources Panel by representatives of the American Association of Petroleum Geologists, the Gas Research Institute, and ICF Resources Incorporated (app. 1). The definition of key terms and the method of analysis employed in each assessment were outlined. The estimates from each study were summarized, and to the extent that the estimates varied, explanations were offered to account for the differences. An independent assessment of recent developments in enhanced oil recovery was also prepared. This background information provided guidelines for the Oil Resources Panel to provide expert judgments in assessing the recoverable portion of the oil resource base of the United States.

Four geographic areas were considered: the lower 48 states onshore, the lower 48 states offshore, Alaska onshore, and Alaska offshore. To be consistent with the approach used by the Department of the Interior and the Energy Information Administration in previous studies, the onshore region was defined to include State waters. Estimates of undiscovered resources and reserve growth were developed. Reserve growth was defined as applying to existing fields and not to undiscovered fields. Therefore, reserve growth included oil recovered as a result of deeper pools, infill drilling, revision of reserves, enhanced oil recovery, and any other additional recovery from existing fields.

U.S. oil resources, as of August 1992, were assessed under two price scenarios and two technology scenarios. The two price scenarios, in constant 1992 dollars, were $20 per barrel and $27 per barrel. In the technology scenarios, technology was broadly defined to include improved geologic and technical knowledge and understanding of the resource, as well as advances in recovery methods, for example, drilling, stimulation, and enhanced oil recovery. Individual estimates were made for what was considered to be the mean recoverable oil, given the price and technology assumptions outlined in each case.

Role of the Oil Resources Panel

The members of the national Oil Resources Panel represented a broad cross section of experts from major oil companies, independent oil companies, Federal government departments and agencies, State geological surveys, private foundations, and consulting firms. The Panel included representatives from all of the agencies or entities involved in previous resource estimates of the U.S. oil resource base. The Panel met August 31 and September 1, 1992, in Austin, Texas, to review and discuss the results of previous resource assessments.

The Oil Resources Panel was presented with the basic data, methodology, assumptions, and results of previous resource assessments (apps. 1–3). Members of the Oil Resources Panel also presented information and assessments of various categories of the resource base for which they had specialized expertise. Mr. Gunn coordinated and brought to the Panel the perspective of the American Association of Petroleum Geologists, and Mr. Skov provided the input and perspective of the Society of Petroleum Engineers. Some of the difficulties in measurement and assessment of recoverable oil resources were discussed. The Panel established its own guidelines and definitions. Each member of the Panel was then asked to provide an estimate, rounded to one decimal place, on the basis of a mean assessment of the oil resource for 28 separate categories (table 1). Each estimate was made in a confidential vote. The arithmetic mean of the votes in all categories was used for the final results presented in this report.

Definitions

The following definitions or characterizations were agreed upon by the Oil Resources Panel:

1. Proved reserves: Reserves already discovered and producible under existing prices and technology; the volume adopted for proved reserves, 25 billion barrels, is that carried at yearend 1991 as proved reserves by the Energy Information Administration.
2. Undiscovered resources: Resources yet to be discovered in newly drilled structures or other geologic configurations and future reserve growth from these discoveries.
3. Reserve growth: Future reserve additions from fields already discovered and with booked reserves at yearend 1991; includes reserves added by extensions, revisions, new pools, infill drilling, and improved recovery techniques; includes mobile and immobile oil recovery.
4. State waters of Alaska and the U.S. lower 48 states are included in onshore categories; offshore resources are restricted to the Federal Outer Continental Shelf, following the Department of the Interior's reporting.
5. Tar sands and oil shales are excluded from the Panel's estimation.
6. Wellhead prices assumed are in 1992 constant dollars and tied to a per-barrel price for West Texas intermediate crude oil.

Table 1. Summary of estimates by the Oil Resources Panel (billion barrels).

	Existing technology ($20/bbl '92)	Advanced technology ($20/bbl '92)	Existing technology ($27/bbl '92)	Advanced technology ($27/bbl '92)
Lower 48 onshore				
Reserve growth	24	45	33	70
Undiscovered resources	24	34	33	48
Subtotal	48	79	66	118
Lower 48 offshore				
Reserve growth	2	3	3	6
Undiscovered resources	11	14	13	17
Subtotal	13	17	16	23
Alaska onshore				
Reserve growth	5	7	7	13
Undiscovered resources	8	12	12	17
Subtotal	13	19	19	30
Alaska offshore				
Undiscovered resources	—	2	4	8
Total undiscovered resources	43	62	62	90
Total reserve growth	31	55	43	89
Total undiscovered resources and reserve growth	74	117	105	179
Proved reserves at yearend 1991	25	25	25	25
Total resources	99	142	130	204

7. Technology: Technology includes hardware and equipment, as well as basic understanding of the resource, ability to deploy technology, and new concepts or strategies. Existing technology is assumed to be technology currently in use, both its nature and the extent of current use. Advanced technology includes new technology and concepts, as well as significantly greater use and novel application of existing technology. For example, 3-D seismic surveying is an existing technology; more extensive use of this existing technology, future advances in data acquisition, processing, and interpretation, as well as advances in extraction methods, are considered advanced technology.

U.S. OIL RESOURCE BASE: RESULTS OF THE PANEL

Historical estimates of the ultimately recoverable oil resource base of the United States reflect three periods: (1) a period from the 1920's through the early 1950's when estimates were very low and conservative, commonly little or no more than the cumulative discoveries of the day; (2) a period from the middle 1950's through the middle 1970's when a large number of estimates were characterized by substantially different assumptions; statistically based estimates were generally lower and conservative, whereas some of the more geologically or volumetrically based estimates were high; by the late 1970's results of the two approaches were generally converging, driven by falling production and common notions of resource scarcity; (3) a more recent period beginning in the early 1980's showing estimates generally increasing, not to the high volumetric estimates of the 1960's but well above the statistically based estimates of the middle 1950's to the early 1980's. Estimates of the past decade reflect increased understanding of the impact of advanced technology in increasing recovery of the remaining resource base and the general view that significant volumes of unrecovered mobile oil exist in geologically complex reservoirs (fig. 1).

The Panel's estimates as of August 1992 are consistent with recent trends—the lowest estimated ultimate recovery (remaining resource plus proved reserves of 25 billion barrels and cumulative production of 164 billion barrels) of 263 billion barrels being near the bottom of recent estimates and the high range, 368 billion barrels, slightly exceeding the current higher range of estimates in figure 1. Estimates of the Panel, based on the existing technology and $27 per barrel scenario (294 billion barrels) and the advanced technology and $20 per barrel scenario (306 billion barrels) are also slightly above the average of recent estimates (fig. 1).

Total Recoverable Resources

The Panel's estimate of total recoverable resources as of August 1992, based on the calculated average of total individual estimates, ranged from 99 billion barrels at a wellhead price of $20 per barrel with existing technology to 204 billion barrels under the assumption of $27 per barrel and advanced technology. The estimate at the lower price, but with advanced technology, was 142 billion barrels, slightly more than the average of the estimate at the higher

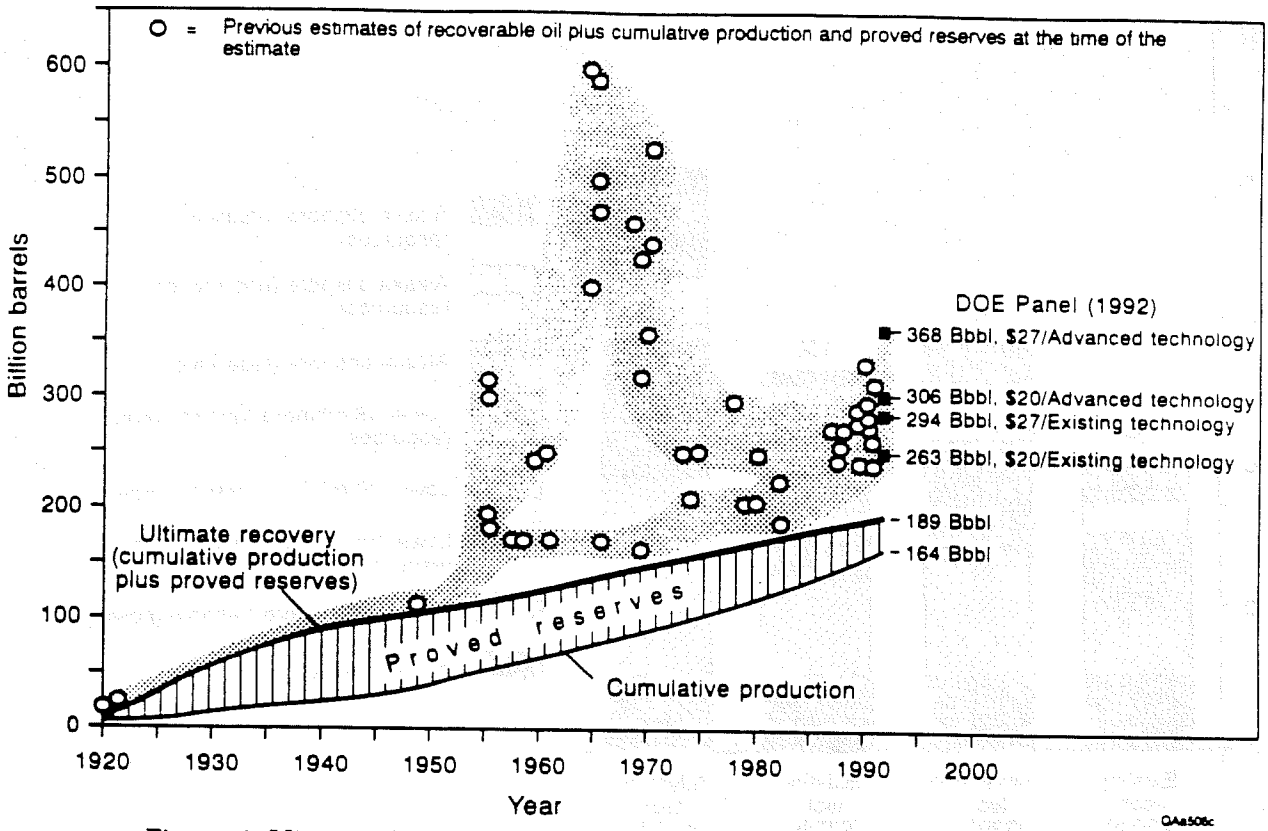

Figure 1. Historical estimate of ultimately recoverable oil resource base.

price level, but with only existing technology. In effect, with the price range considered, recoverability of the remaining U.S. oil resource base is as sensitive to technology as it is to price (fig. 2).

Future potential was estimated by the Panel, under conditions assumed, to be nearly equally divided between reserve growth from existing fields and resources from new fields to be discovered along with the reserve growth these new discoveries will experience. About two-thirds of the remaining total undiscovered resources and reserve growth exists onshore in the lower 48 states, owing to the substantial potential of reserve growth in existing fields and to substantial undiscovered resources (table 1). The remaining one-third of U.S. potential is in the U.S. offshore and in Alaska, where the potential for large-field discovery is generally greater than onshore in the lower 48 states.

Proved Reserves

The Panel adopted the 1991 yearend proved reserves provided by the Energy Information Administration—24.7 billion barrels. Over the past 5 years, reserve growth from existing fields has contributed an average of 2.1 billion barrels per year, whereas new field discoveries have amounted to 95 million barrels per year, a volume that should appreciate (if historical field appreciation factors are used) with future reserve

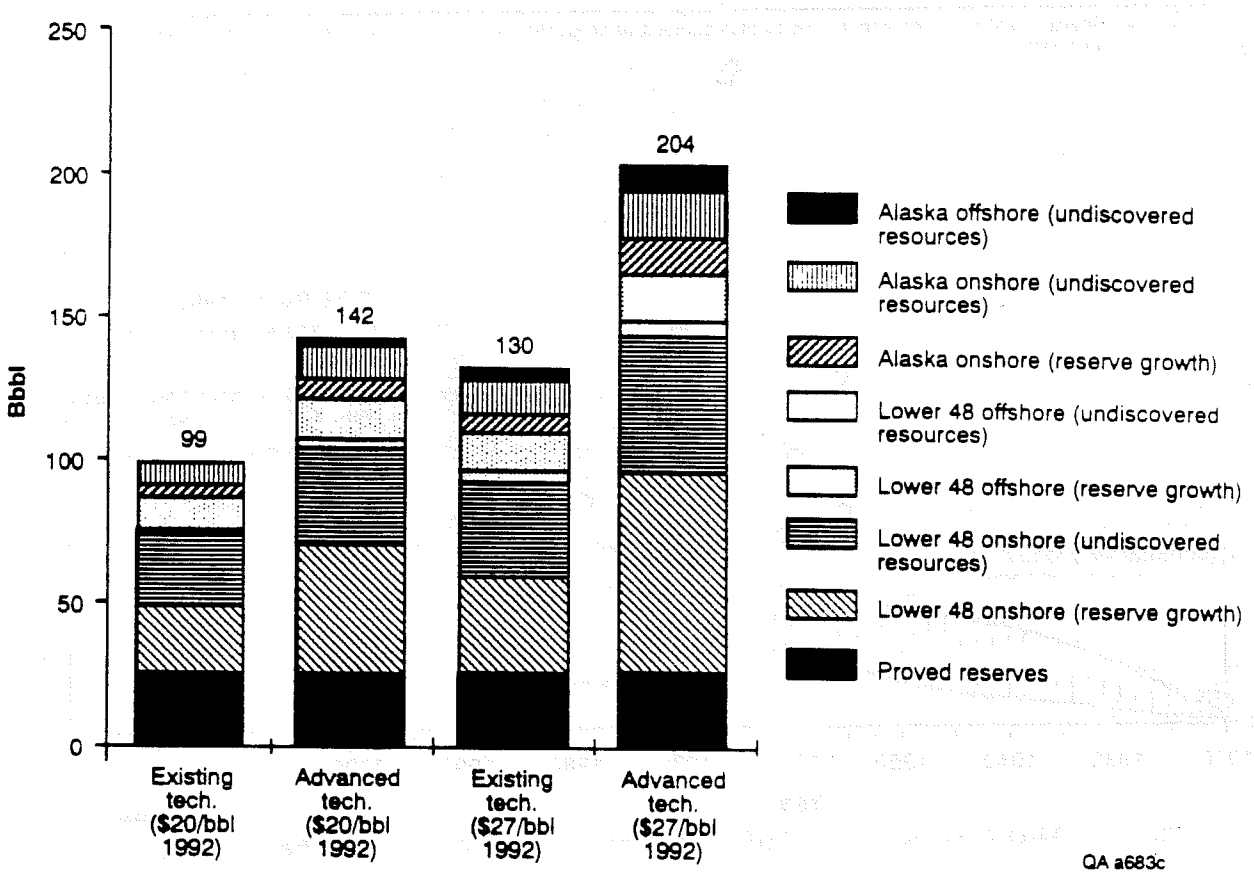

Figure 2. Reserve growth, undiscovered resources, and proved reserves.

growth to about 750 million barrels. The total additions of 2.2 billion barrels contrast with an average annual production over the period of 2.7 billion barrels.

Undiscovered Resources

The average of estimates by the Oil Resources Panel for undiscovered resources at $20 per barrel ranged from 43 billion barrels with existing technology to 62 billion barrels with advanced technology. Under the assumption of a $27-per-barrel wellhead price, existing technology will allow recovery of an average of 62 billion barrels, whereas advanced technology, fully deployed, will yield 90 billion barrels. Advanced technology increased recoverable volumes by about 45 percent at both price levels (figs. 3 and 4).

More than half of the yet-to-be-discovered oil potential is judged to exist in the onshore lower 48 states, although most of the oil provinces of the lower 48 states are generally perceived as mature in exploration. However, in addition to mature oil provinces, there are a number of high potential basins that are yet to be fully explored. The Oil Resources Panel points to these only partly explored basins, especially at intermediate and greater depths, and to the role such technologies as 3-D seismic surveying will play in increasing efficiency in the discovery of subtle or small traps.

Although exploration potential in the onshore lower 48 and the more frontier areas

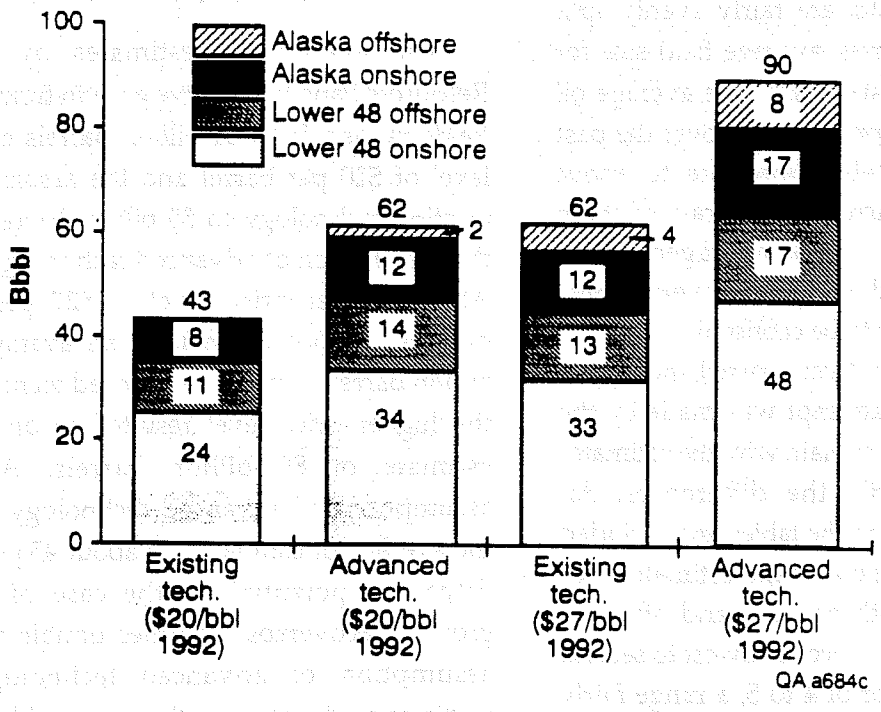

Figure 3. Undiscovered resources (price and technology scenarios).

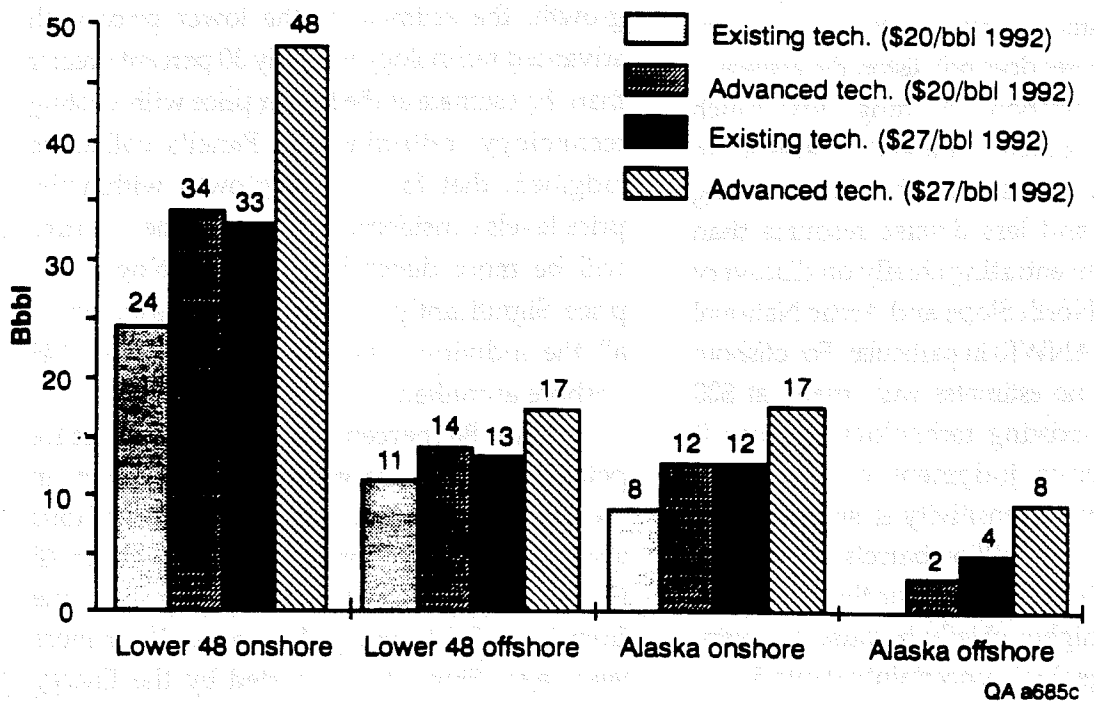

Figure 4. Undiscovered resources (geographic area).

offshore and in Alaska are fairly evenly split relative to total volumes, average field size for discovery differs substantially. The average oil field discovered onshore lower 48 over the past 5 years will ultimately appreciate to about 750,000 to 1 million barrels. By contrast, offshore lower 48 discoveries have averaged about 20 million barrels, and Alaska discoveries must be substantially larger to be economic.

As expected with a diverse panel, individual estimates varied. No attempt was made by the Oil Resources Panel to explain why the estimates varied or to reconcile the differences. All estimates are reported in the tables and included in the calculation of the average estimates. For the U.S. lower 48, both onshore and offshore, the estimate range from second lowest to second highest was by a factor of 4 to 5, a range fairly consistent under different assumptions of price and technology (tables 2 and 3). In tables 2 through 5, with the exception of the advanced technology and $27 per barrel oil price for undiscovered resources in the lower 48 onshore, the median is consistent with the average. As a result, the presence of very optimistic or very pessimistic estimates does not distort the average.

For Alaska onshore the range was much lower, generally a factor of about 2 (table 4). In the case of onshore Alaska, the Panel was dealing with a smaller and less diverse resource than the lower 48, concentrating chiefly on discovery potential of the North Slope and Arctic National Wildlife Refuge (ANWR) in particular. For offshore Alaska (table 5), no estimates were made at $20 per barrel and existing technology because it was the collective judgment of the Panel members that price sensitivity is such that the estimates would be 1 billion barrels or less. The range in individual estimates for the remaining categories was higher chiefly because of a very high degree of geologic uncertainty (table 5).

Reserve Growth

The average of estimates by the Oil Resources Panel for reserve growth from existing fields ranged from 31 billion barrels at a price level of $20 per barrel and the assumption of existing technology to 55 billion barrels under the assumption of advanced technology (fig. 5). At the higher price level of $27 per barrel, existing technology yielded an average of 43 billion barrels, whereas advanced technology at the higher price level resulted in an average estimate of 89 billion barrels. Although assumptions of advanced technology increase the average of estimates by about 45 percent in discovery potential, in the case of reserve growth, recoverable volumes double with the assumption of advanced technology. For undiscovered resources, the recoverable volume at the lower price with advanced technology is equal to the estimated volume at the higher price with only existing technology, reflecting equal sensitivity to price and technology in the considered range (fig. 3). In the case of reserve growth, the estimate at the lower price with advanced technology is nearly 30 percent greater than the estimate at the higher price with existing technology, reflecting the Panel's collective judgment that for reserve growth within the price levels considered, recovery of the resource will be more dependent on technology than price. Significantly, this relationship is shown in all the individual estimates for the lower 48 onshore as ranked.

About 80 percent of the judged future potential for reserve growth exists onshore in the lower 48 states because the vast bulk of total unrecovered oil is onshore in the lower 48 (fig. 6). Most of the potential recovery will come from large fields, many discovered 30 or more years ago. From data reported by the Energy

Table 2. Estimates of undiscovered resources—lower 48–onshore (billion barrels).

	Undiscovered resources			
	Existing technology ($20/bbl '92)	Advanced technology ($20/bbl '92)	Existing technology ($27/bbl '92)	Advanced technology ($27/bbl '92)
	4	8.3	5.2	10.7
	10	15	14	18
	10	15	20	25
	20	25	22	30
	20	25	23	30
	21	26	25	30
	22	26	25	31
	22	30	27	35
	25	35	30	50
	28	40	34	50
	28	42	35	50
	30	45	40	56
	30	48	40	65
	39	50	65	100
	40	60	65	100
	40	60	65	100
Average	**24**	**34**	**33**	**48**
Median	**25**	**30**	**30**	**35**
Standard deviation	**10.3**	**15.3**	**17.5**	**28.4**

Table 3. Estimates of undiscovered resources—lower 48–offshore (billion barrels).

	Undiscovered resources			
	Existing technology ($20/bbl '92)	Advanced technology ($20/bbl '92)	Existing technology ($27/bbl '92)	Advanced technology ($27/bbl '92)
	4.5	7	6	8
	5	8	8	11
	6	8.5	8	11.2
	6.5	8.5	9	12
	6.6	9.8	9.2	12
	6.7	10	10	14
	7	12	10.5	15
	9	12	11	15
	10	12	12	15
	10	12	12	16
	10	12	12	17
	10	13	12	18
	12	16	14	19
	15	16	17	20
	15	17	17	25
	20	22	23	42
	30	38	38	
Average	**11**	**14**	**13**	**17**
Median	**10**	**12**	**12**	**15**
Standard deviation	**6.4**	**7.3**	**7.5**	**7.9**

Table 4. Estimates of undiscovered resources—Alaska onshore (billion barrels).

	Undiscovered resources			
	Existing technology ($20/bbl '92)	Advanced technology ($20/bbl '92)	Existing technology ($27/bbl '92)	Advanced technology ($27/bbl '92)
	2	5	6	8
	5	6	8	12
	5	7	9	12
	5	9	10	14
	7	10	10	15
	8	10	12	15
	8	10	12	15
	8	11.3	13	15.3
	9	12	13	16
	9.2	13	13	18
	9.9	14	13	20
	10	15	13.2	20
	10	15	14	20
	10	15	14	20
	10	15	14	21
	11	15.8	15	22.4
	12	16	16	22.4
Average	**8**	**12**	**12**	**17**
Median	**9**	**12**	**13**	**16**
Standard deviation	**2.6**	**3.5**	**2.6**	**4.1**

Table 5. Estimates of undiscovered resources—Alaska offshore (billion barrels).

	Undiscovered resources			
	Existing technology ($20/bbl '92)	Advanced technology ($20/bbl '92)	Existing technology ($27/bbl '92)	Advanced technology ($27/bbl '92)
	not considered	0	0	0
		0	1	1
		0	1	3
		0	1	3
		0	1.5	4
		1	2	5
		1	2	6
		1.5	2	6
		1.5	3	12
		2	3	12
		2	5	12
		2	8	12.5
		3	8	14
		3.5	8	14
		5	8	21
		11	8	
			14	
Average		**2**	**4**	**8**
Median		**1.5**	**3**	**6**
Standard deviation		**2.8**	**3.9**	**6.0**

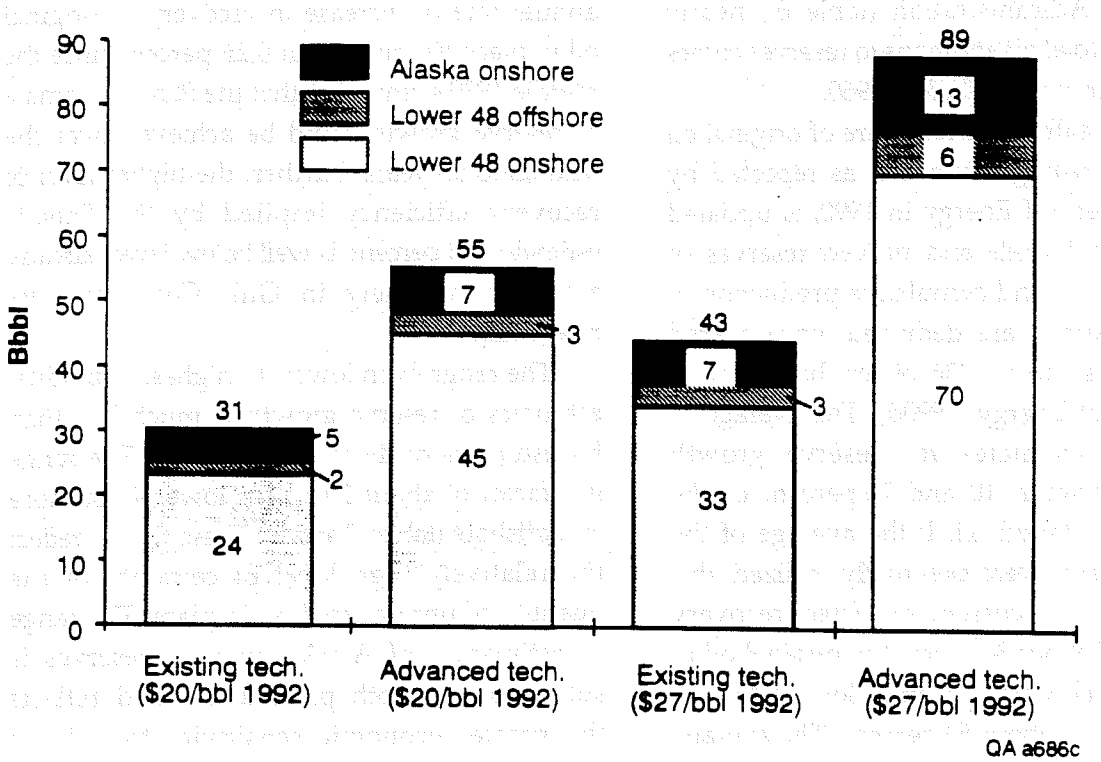

Figure 5. Reserve additions from future reserve growth (price and technology scenarios).

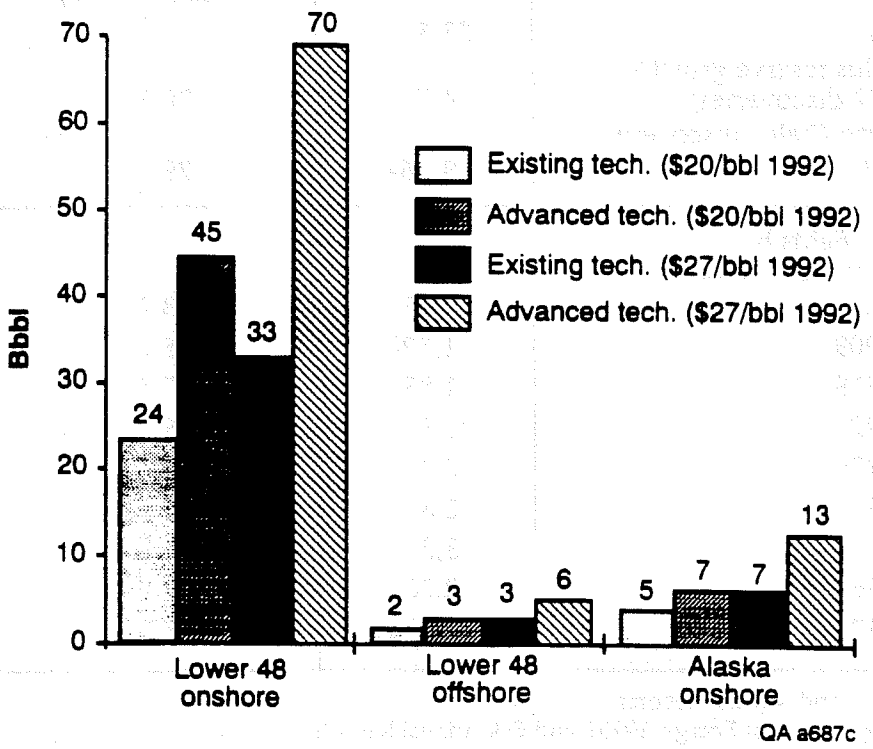

Figure 6. Reserve additions from future reserve growth (geographic area).

Information Administration (table 6), nearly 60 percent of total oil additions to reserves comes from discoveries made before 1960.

If the 513-billion-barrel figure of original oil in place in existing reservoirs, as reported by the Department of Energy in 1990, is updated to 525 billion barrels and proved reserves of 25 billion barrels and cumulative production of 164 billion barrels are deducted, unrecovered oil is estimated to be 336 billion barrels (U.S. Department of Energy, 1990d). The average of the various estimates for reserve growth represents between 10 and 25 percent of the existing unrecovered oil. If the average of the Panel's estimates were eventually realized, this would move the current expected recovery efficiencies of about 36 percent of original oil in place to a level ranging from a low of 42 percent to a high of about 53 percent. The average annual rate of increase in recovery of original oil in place has run about 0.25 percent since the middle 1970's, implying that the Panel's estimate of reserve growth could be achieved over the next 25 to 65 years. Further, the higher level of recovery efficiency implied by the Panel's estimates, 53 percent, is well below levels already achieved routinely in Gulf Coast onshore reservoirs.

The range from lowest to highest individual estimates of reserve growth is much less than for estimates of discovery potential. The range is a factor of about 2 to 3 for lower 48 onshore and offshore (tables 7 and 8). These figures reflect the relatively high level of certainty of the quantity of unrecovered oil in place. The range in estimation of Alaska onshore reserves is substantial at both price levels and reflects the greater economic sensitivity for Alaska

Table 6. Composition and source of U.S. lower 48 oil additions, 1977–1987 (million barrels).

		Additions (%)
Total additions	23,554	
Discovery (plus reserve growth of post-1977 discoveries)	4,790	20.3
Reserve growth (fields discovered before 1977)	18,764	79.7
Reserve growth (fields by decade of discovery, before 1977)		
pre-1900	751	3.2
1900–1909	1,320	5.6
1910–1919	1,831	7.8
1920–1929	1,350	5.7
1930–1939	2,441	10.4
1940–1949	2,511	10.7
1950–1959	3,341	14.2
1960–1969	2,229	9.5
1970–1979	2,990	12.7

Sources: EIA 1990 and Annual Reports
U.S. Department of Energy, 1990d, and EIA Annual Reports

Table 7. Estimates of reserve growth—lower 48 onshore (billion barrels).

	Reserve growth			
	Existing technology ($20/bbl '92)	Advanced technology ($20/bbl '92)	Existing technology ($27/bbl '92)	Advanced technology ($27/bbl '92)
	16	30	24	48
	17	34	25	50
	18	40	26	50
	19	40	30	55
	20	42	30	60
	22	42	30	65
	22	45	32	65
	24	45	33	70
	25	45	35	70
	25	45	35	75
	25	45	35	75
	25	48	35	75
	26	50	36	80
	27	50	37	80
	28	50	40	82
	30	54	40	85
	31	55	44	100
Average	**24**	**45**	**33**	**70**
Median	**25**	**45**	**35**	**70**
Standard deviation	**4.4**	**6.5**	**5.5**	**14.1**

Table 8. Estimates of reserve growth—lower 48 offshore (billion barrels).

	Reserve growth			
	Existing technology ($20/bbl '92)	Advanced technology ($20/bbl '92)	Existing technology ($27/bbl '92)	Advanced technology ($27/bbl '92)
	1	0.34	1.5	3
	1	1.5	2	3
	1	2	2	4
	1	2	2	4
	1.5	3	2.2	4
	2	3	2.5	5
	2	3	3	5
	2	3	3	5
	2	3	3	5.1
	2	3.3	3	6
	2.3	3.4	3	6
	2.3	4	3.5	6
	2.7	4	3.7	6
	3	4	4	8
	3	4	4	10
	4	7	7	10
	6	7	7	10
Average	**2**	**3**	**3**	**6**
Median	**2**	**3**	**3**	**5.1**
Standard deviation	**1.3**	**1.7**	**1.6**	**2.3**

Table 9. Estimates of reserve growth—Alaska onshore (billion barrels).

	Reserve growth			
	Existing technology ($20/bbl '92)	Advanced technology ($20/bbl '92)	Existing technology ($27/bbl '92)	Advanced technology ($27/bbl '92)
	1	1.5	1.5	2.5
	1	3	2	7
	2	3.5	3	8
	2.5	4	5.5	9
	3	6	6	10
	5	6	6	10
	5	6	6	10
	5	6.5	7	11
	5	7	7	12
	6	8	7	12
	6	8	8	15
	6	8.5	8	15
	6	9	8	16
	6.5	9	8	16
	6.5	9.5	8	20
	8	15	9.5	29
			10	
Average	**5**	**7**	**7**	**13**
Median	**5**	**6.75**	**7**	**11.5**
Standard deviation	**2.1**	**3.2**	**2.4**	**6.1**

(table 9). Estimates were not made for Alaska offshore reserve growth because no discoveries have been posted to date.

Comparison with Previous Estimates

A number of estimates of remaining U.S. recoverable oil resources have been made and published in recent years. These estimates and the methodology employed are summarized in appendix 1. These previous estimates utilize different assumptions of price and technology and are only generally comparable with the Panel's estimates. Still, significant differences between the summary of the Panel results and the previous estimates are worth noting (table 10).

The Panel's average estimates for total recoverable resources are higher than the average of previous estimates at the lower price level and they are approximately the same at the higher price level. Reserve growth estimates by the Panel, with one exception, are lower than previous estimates. The average of the Panel's estimates for undiscovered resources at an oil price of $20 per barrel is about 40 to 45 percent higher than previous estimates for the frontier areas of the U.S. offshore and Alaska, but 40 to 90 percent higher for the onshore lower 48 states.

Table 10. Average of Panel's estimates compared with average of recent estimates (billion barrels of oil, exclusive of proved reserves).[a]

	Existing technology $20	Advanced technology $20	Existing technology $27	Advanced technology $27
Undiscovered resources				
Onshore lower 48	24 (17)	34 (18)	33 (19)	48 (22)
Offshore lower 48	11 (6)	14 (9)	13 (9)	17 (11)
Onshore Alaska	8 (7)	12 (9)	12 (13)	17 (14)
Offshore Alaska	– (1)	2 (2)	4 (11)	8 (14)
Total undiscovered	43 (31)	62 (38)	62 (52)	90 (61)
Reserve growth				
Onshore lower 48	24 (19)	45 (55)	33 (48)	70 (113)
Offshore lower 48	2 (1)	3 (3)	3 (2)	6 (3)
Onshore Alaska[b]	5 (4)	7 (4)	7 (3)	13 (5)
Total reserve growth	31 (24)	55 (62)	43 (53)	89 (121)
Total oil resources	74 (55)	117 (100)	105 (105)	179 (182)

Notes:

(a) The average of other recent estimates is in parentheses.

(b) The estimates in parentheses for this category include estimates for offshore Alaska.

Other Factors Affecting Resource Potential

Several factors may affect the potential for recoverable oil as estimated by the Oil Resources Panel. These factors include downsizing of research and development efforts in the private sector, access restrictions, environmental regulations, and premature field abandonment. The advanced technology scenarios presuppose that research and development will be done to realize that technology. This may not happen, as there has been a downsizing of research and development efforts in the private sector in recent years. Clearly, physical access to a resource is necessary if the resource is to be developed. Environmentally sound development of oil resources is a requisite, but if the costs of regulation added to other operating costs exceed the potential value of the resource, it will obviously not be realized and the oil actually recovered will be lower than the Panel estimates. Finally, as has been pointed out by the Department of Energy (U.S. Department of Energy, Bartlesville Project Office, 1989), the rate of abandonment of existing fields is critical. To the extent fields are abandoned before projected reserve growth is realized, resource potential will not be realized at the prices here assumed.

CONCLUSIONS

The Panel's collective judgment indicates that ample oil resources in the United States are technically recoverable with existing to advanced technology at current to moderate wellhead prices. The range of 99 to 204 billion barrels, reported as the average of four price-technology categories, is equivalent to 35 to 75 years of production at the current annual rate of 2.7 billion barrels.

The Panel's estimates reflect a trend of generally increasing recoverable oil estimates as published over the past 10 years. The estimates are not as high as those made by some analysts in the 1960's, using volumetric and basin analog models. However, they are substantially higher than the statistically based estimates of the 1960's and 1970's, which contributed to the perception that was common in the 1970's that the U.S. oil resource base was rapidly depleting.

Although the remaining recoverable portion of the U.S. resource base is ample, even large in the aggregate, it differs from the part of the resource base that has already been developed. Few opportunities exist for giant field discovery and the substantial economy of scale such discovery historically offered. Most of the remaining resource base in the United States is convertible to producible reserves in relatively small increments, whether through exploration or reserve growth development. Economies of scale have changed to economies of efficiency. Certainly, the exploration for and the development and production of oil have long had strong technological components, but today and in the future, technological dependence will be foremost. Even most of the large fields potentially existing for future discovery are in relatively high cost areas, making technology and associated cost reductions very important. These basic differences in the resource base are reflected clearly in the sensitivity of the Panel's estimate to technology assumptions. The fact that the Panel's estimates are somewhat higher than recent resource estimates, particularly in the area of undiscovered resources, is a further reflection of the perceived importance of technology and improved geologic understanding.

REFERENCES

American Association of Petroleum Geologists, 1989, Position paper on U.S. oil resource estimates: AAPG Explorer, v. 10, no. 4, 2 p.

Fisher, W.L., 1988, The technological dependency of the remaining oil and gas resource base in the U.S.: presentation to Society of Petroleum Engineers, Symposium on Energy, Finance, and Taxation Policies, Washington, D.C.

Flawn, P.T., Gunn, R., and Massad, A., 1990, Report by Committee on Reserves and Resources, Governor's Energy Council, State of Texas, 4 p.

Galloway, W.E., Ewing, T.E., Garrett, C.M., Tyler, Noel, and Bebout, D.G., 1983, Atlas of major Texas oil reservoirs: The University of Texas at Austin, Bureau of Economic Geology, 139 p.

Kuuskraa, V.A., McFall, K.S., and Godec, M.L., 1990, U.S. petroleum and natural gas resources, reserves and extraction costs: Fairfax, Va., ICF Resources, Inc., Report prepared for the National Research Council Committee on Production Technologies for Liquid Transportation Fuels, 83 p.

National Petroleum Council, 1976, Enhanced oil recovery: Washington, D.C., NPC, 231 p.

National Petroleum Council, 1984, Enhanced oil recovery: Washington, D.C., NPC, 96 p.

National Research Council, 1991, Undiscovered oil and gas resources, an evaluation of the Department of the Interior's 1989 assessment procedures: Washington, D.C., National Academy Press, 179 p.

Root, D.H., and Attanasi, E.D., 1992, Oil field growth in the United States—how much is left in the barrel?: USGS Research on Energy Resources, 1992, Program and Abstracts, Eighth V.E. McKelvey Forum on Mineral and Energy Resources, USGS Circular 1074, 1 p.

U.S. Department of Energy, 1989, Major program elements for an advanced geoscience oil and gas recovery research initiative: Prepared by the Geoscience Institute for Oil and Gas Recovery Research, The University of Texas at Austin, DOE/BC-89/9/SP, 50 p.

U.S. Department of Energy, 1990a, Hydrocarbon geoscience research strategy: DOE/FE-0186P, 49 p.

U.S. Department of Energy, 1990b, Oil research program implementation plan: DOE/FE-0188P, 144 p.

U.S. Department of Energy, Bartlesville Project Office, 1989, Abandonment rates of the known domestic oil resource: DOE/BC-89/6/SP, 39 p.

U.S. Department of Energy, Energy Information Administration, 1990c, The domestic oil and gas recoverable resource base: supporting analysis for the National Energy Strategy: SR/NES/90-05, 56 p.

U.S. Department of Energy, Energy Information Administration, 1990d, U.S. oil and gas reserves, by year of discovery: DOE/EIA-0534, 137 p.

U.S. Department of Energy, Energy Information Administration, 1991, U.S. crude oil, natural gas, and natural gas liquids reserves—1990 annual report: DOE/EIA-0216(90), 109 p.

U.S. Department of Energy, in cooperation with the State of Alaska, 1991, Alaska oil and gas: energy wealth or vanishing opportunity?: DOE/ID/01570-H1, 274 p.

U.S. Department of the Interior, 1989, Estimates of undiscovered conventional oil and gas resources in the United States—a part of the Nation's energy endowment: 44 p.

U.S. Department of the Interior, 1991, Estimates of undiscovered economically recoverable oil & gas resources: OCS Report, MMS 91-0051, 30 p.

APPENDIX 1. REVIEW AND COMPARISON OF RECENT ASSESSMENTS OF THE OIL RESOURCE BASE OF THE UNITED STATES

INTRODUCTION

In recent years, several studies have been undertaken to assess the U.S. oil resource base. It is clear from these studies that the resource base is substantial. Although the method of analysis in each study differs, typically moderate and high price scenarios are used. In some studies, price scenarios are used in conjunction with comparisons of the impact of existing and advanced technologies. The purpose of this review is to summarize and compare the major oil resource assessments undertaken in the past 5 years. The review will include resource estimates made by the U.S. Department of the Interior, the Energy Information Administration, the American Association of Petroleum Geologists, the Governor's Energy Council of the State of Texas, the National Research Council, the U.S. Department of Energy, the Geoscience Institute for Oil and Gas Recovery Research, and a joint study by the U.S. Department of Energy and the State of Alaska.

The method of analysis used in each study is summarized in Part I. As most of the studies reviewed here used the Department of Energy's Tertiary Oil Recovery Information System (TORIS), it will also be discussed. In Part II resource estimates from the various studies for four regions are compared: the lower 48 states, onshore; the lower 48 states, offshore; Alaska, onshore; and Alaska, offshore. Two categories of resource estimates are examined: undiscovered resources and reserve growth.

PART I

A. U.S. Department of the Interior (1989)

Undiscovered Resources

The foundation of most recent assessments of undiscovered resources is a report published in 1989 by the Department of the Interior (DOI), *Estimates of Undiscovered Conventional Oil and Gas Resources in the United States—A Part of the Nation's Energy Endowment*. This report, also referred to as the "National Resource Assessment," was based on data and information available as of January 1, 1987. Estimates were provided for undiscovered conventionally recoverable oil resources located outside of known oil fields. Conventionally recoverable oil included oil producible by natural pressure, pumping, or injection of water or gas. The assessment did not include "unconventional" sources of oil (i.e., tar deposits, intractable heavy oil deposits, oil shale, and oil synthesized from organic sources such as coal).

The United States was divided into nine onshore regions and four offshore regions (table A1-1). The onshore regions included State waters. The offshore included the Outer Continental Shelf (OCS) and Exclusive Economic Zone adjacent to the lower 48 states and Alaska. The U.S. Geological Survey (USGS) prepared the estimates for the onshore and State offshore provinces, and the Minerals Management Service (MMS) prepared the estimates for the Federal offshore. Resource estimates were presented in two categories. *Undiscovered recoverable resources* referred to accumulations of sufficient size and quality that could be produced with conventional recovery technologies without regard to commercial economic viability. *Undiscovered economically recoverable resources* referred to that part of the undiscovered recoverable resource that is economically recoverable (i.e., commercially profitable) by current conventional technologies and with specific economic assumptions:

- an oil price of $18 per barrel (bbl) for January 1, 1987
- 1987–1989: oil prices, in constant 1987 dollars, decrease 3 percent annually
- 1990 on: oil prices, in constant 1987 dollars, increase 4 percent annually
- inflation at 4 percent annually from 1987 to 1990
- 7 percent annual inflation for 1991 and beyond
- exploration costs not included
- except for the onshore lower 48 states where pipelines are in place, transportation and pipeline development costs were included

Table A1-1. Assessment of undiscovered conventional crude oil—range of probability estimates (billion barrels).

	Undiscovered recoverable resources			Undiscovered economically recoverable resources		
	F_{95}	Mean	F_5	F_{95}	Mean	F_5
Onshore and state waters						
Alaska	3.6	13.2	31.3	1.1	7.9	23.8
Pacific coast	1.5	3.5	6.6	1.4	3.4	6.5
Colorado	0.5	1.5	3.4	0.4	1.5	3.3
Rocky Mountains and Northern Great Plains	2.7	4.5	6.9	2.2	3.8	6.0
West Texas and eastern New Mexico	1.5	2.6	4.0	1.4	2.4	3.8
Gulf coast	2.4	4.2	6.7	2.2	4.0	6.5
Midcontinent	1.2	1.9	2.7	1.1	1.7	2.5
Eastern interior	1.3	1.8	2.4	1.3	1.8	2.4
Atlantic	0.1	0.2	0.5	0.1	0.2	0.5
Total onshore and state waters	**19.6**	**33.3**	**51.9**	**13.9**	**26.6**	**45.0**
Federal offshore						
Alaska	0.6	3.4	9.4	0.0	0.9	4.8
Pacific coast	0.9	3.4	8.3	0.4	2.0	5.5
Gulf of Mexico	4.9	8.6	13.6	2.6	5.0	8.6
Atlantic coast	0.1	0.7	2.3	0.0	0.2	0.8
Total federal offshore	**9.2**	**16.1**	**25.6**	**4.0**	**8.2**	**14.3**
Total United States	**33.2**	**49.4**	**69.9**	**20.7**	**34.8**	**53.8**

Notes:

1. Source: U.S. Department of the Interior, 1989, *Estimates of undiscovered conventional oil and gas resources in the United States—a part of the Nation's energy endowment*, Table 2, p. 19.
2. Mean value totals may not be equal to the sums of the constituent means because numbers have been independently rounded.

Undiscovered accumulations were assigned a January 1, 1987, discovery date and were considered to be economically recoverable if projected cash flows were sufficient to pay development and operating costs and to provide an after-tax rate of return of 8 percent (plus or minus 2 percent). This approach was used to calculate a "minimum economic field size" (MEFS), which was an estimate of the smallest field that could be developed and have a positive private economic value. The MEFS cutoff was applied to the field size populations of assessed undiscovered resources thought to be recoverable by conventional production methods. All estimated accumulations smaller than the MEFS were excluded from the *undiscovered economically recoverable resources* category.

The estimates for undiscovered oil resources were based on compilation and analysis of geologic, geophysical, engineering, and economic data from published and private sources throughout government and industry. For the onshore regions and State waters, computerized drilling and completion data from exploratory and development wells were used. Annual and cumulative drilling statistics were developed from this data base. For the Federal offshore, the MMS used data received from industry exploration and development operations performed under permits or mineral leases issued for OCS areas. In cases where insufficient data were available, data from geologically similar provinces from the United States and abroad were used.

In the 80 petroleum provinces studied by the USGS, a play analysis was used for accumulations greater than 1 million barrels (MMbbl) of oil. Judgments were made as to the probability of occurrence of the geologic factors necessary for the formation of oil accumulations, and accumulation sizes and numbers were quantitatively assessed as probability distributions: 5 percent probability, mean value, and 95 percent probability (table A1-1). The computer package FASPF (Fast Appraisal System for Petroleum-Field Size) performed the resource calculations. Probabilistic estimates of recoverable oil in accumulations smaller than 1 MMbbl were made separately. The MMS used the computer mathematical simulation model PRESTO (Probabilistic Resource Estimates—Offshore). This model performed multiple simulations of industry exploratory drilling efforts for potential prospects and ranked possible outcomes of such efforts, which proved economically successful in terms of resources discovered and probabilities of occurrence.

Reserve Growth

The USGS and MMS estimates in the DOI report were based on an analysis of the historical growth of fields using a data series from the American Petroleum Institute (API) that had data through to 1979. From this analysis, the USGS and MMS derived growth estimates that relate future increases in oil recovery to the age of domestic oil fields. The estimates were calculated with API data on past field discovery through to 1979 and did not capture more recent shifts in field development.

A recent report by USGS provided projections for future field growth from known fields in the lower 48 states. The projections, which varied from 10 to 80 billion barrels (Bbbl) of oil, were found to be sensitive to choices made in the analysis concerning the level of aggregation between large and small fields, the number of successive years of data used, and the cutoff age beyond which fields are assumed no longer to grow. Future growth estimates were also found to be sensitive to the industry conditions prevailing during the period when the historical estimates of ultimate field sizes were made (Root and Attanasi, 1992).

B. Energy Information Administration (1990)

Undiscovered Resources

The EIA investigated the impact of possible increases in recoverable resources either through changes to current regulations and legislation to provide access to areas that are subject to restriction or through improved exploration and production technology. The results of this investigation were published in the 1990 report, *The Domestic Oil and Gas Recoverable Resource Base: Supporting Analysis for the National Energy Strategy* (U.S. Department of Energy, Energy Information Administration, 1990c). Areas of restricted access in onshore regions consisted of designated Wilderness, recommended Wilderness, and Wilderness Study Areas. In the offshore, the study examined the tracts covered by the June 26, 1990, Presidential announcement on offshore leasing. It was assumed that all restrictions would be removed for an entire class of affected areas.

The EIA study provided estimates of resource potential under four scenarios: reference, access, advanced technology, and combined access and advanced technology. The reference case was considered as a subset of an overall recoverable target, from which certain portions were deducted because of

access restrictions or limitations on technology. The access case allowed for exploitation of all areas, but with only existing technology. The advanced technology case was based on an assumption of substantial technological development with continuation of restrictions on access in selected areas. The combined access and advanced technology case included the gains from both access to all areas of the United States and advances in technology. In all four scenarios, the results were for economically recoverable estimates. The estimates were based on a 40-year time horizon (1990–2030). The EIA study incorporated many of the economic assumptions used in the 1989 Department of the Interior study of undiscovered resources. For example, in the reference case based on current technology and current cost, an initial oil price of $18 per barrel in 1987 constant dollars was used. The oil price was escalated to about $27 per barrel as the projections went forward in time.

In the advanced technology scenario, the EIA focused on technological innovations that were considered to be operationally viable by 2030 (i.e., techniques for which industry had started development). The EIA considered improvements in technology affecting either the extent of the effective application of the techniques in any given reservoir or the costs of discovery and production. Oil shale was not included because its economic exploitation was considered unlikely given expected economic conditions and anticipated technological development. The EIA also assumed that advanced technology would increase recovery by extending the productive life of fields in general and make possible recovery from fields in locations, such as deep waters, that would otherwise be uneconomic to develop. Recent technological developments included in the analysis were better reservoir data collection and analysis, enhanced reservoir characterization and simulation, improved exploration technologies, horizontal drilling and completion, improved enhanced oil recovery (EOR), enhanced production technology, and superior hydrocarbon extraction techniques under adverse geological or geographic conditions.

The mean values for the *undiscovered economically recoverable resource* estimates of the 1989 DOI study were used as the basis for the estimates in the reference case. The *undiscovered recoverable resource* estimates (i.e., technically recoverable) of the DOI study were used as the basis for estimates in the advanced technology case. Therefore, it was assumed that technological improvements would lower costs sufficiently so that all volumes considered to be technically recoverable would become economically recoverable. The EIA stated that the economic assumptions in the DOI study might restrict the expected recovery to conservative levels. The EIA appears to have increased the DOI estimates somewhat (compare tables A1-1 and A1-2).

The EIA assumed that the impact of advanced technology would be limited in terms of incremental recovery of onshore resources because current technology and practices were considered effective in achieving most of the possible recovery from these fields. As a result, the potential impact of advanced technology in the recovery of onshore resources may have been understated. On the other hand, the EIA may have overstated the impact of the removal of access restrictions. The EIA assumed that all restrictions would be removed. This would be an extreme case and is unlikely. The restrictions are in place for various reasons, including military, safety, and environmental concerns. In practice, if restrictions were removed, they would probably be removed in selected areas only and the removal might be phased in over several years.

Reserve Growth

The EIA suggested that the USGS estimates for inferred reserves were low because of limitations within the data and the fact that the USGS methodology assumed that the relatively old fields quit growing at the time the inferred reserve estimate was made (U.S. Department of Energy, Energy Information Administration, 1990c). In an effort to address this, the EIA developed a data base that contained the year of discovery and estimated the ultimate recovery (cumulative production plus proved reserves) for the years 1977 through 1988. This data base, the Oil and Gas Integrated Field File (OGIFF), revealed significant growth in estimates of ultimate recovery during the 11-year period for fields discovered throughout the past century.

The OGIFF used in the 1990 report by the EIA contained more recent and detailed information on field growth than that captured in the 1989 report by the DOI. The EIA used these data to derive growth factors for inferred reserves within the lower 48 states with a more up-to-date time horizon and with data reflecting more current recovery practices. The EIA constructed a data base of growth factors that

Table A1-2. Estimates of recoverable resources in undiscovered fields[1] (billion barrels).

	Case			
	Reference	Access	Advanced technology	Access & advanced technology
Crude oil				
Lower 48 states	25.4	27.8	41.0	45.0
Conventional	25.4	27.8	31.2	35.2
Onshore	19.3	19.4	20.5	20.7
Offshore[3]	6.2	8.4	10.6	14.5
Discovered bitumen and undiscovered heavy oil	0.0	0.0	9.8	9.8
Alaska[4]	13.1	16.0	25.2	30.0
Total U.S. crude oil[2]	38.6	43.8	66.2	75.0

Notes:

1 Source: U.S. Energy Information Administration, 1990, *The domestic oil and gas recoverable resource base: supporting analysis for the National Energy Strategy*, Table 1, p. 8.

2 Individual values may not add to total because of independent rounding.

3 Estimate for lower 48 federal offshore only. It does not include state offshore.

4 The estimates for Alaska are for all unproved reserves, approximately one-half of which are from undiscovered fields. For example, in the access and advanced technology case, 16.6 billion barrels of the 30.0 billion-barrel total, are from undiscovered fields.

showed the percentage change in estimates of ultimate recovery that occurred between successive years after field discovery. Because of a lack of field development data for Alaska, the EIA relied on the USGS estimates for the assessment of Alaskan inferred reserves.

A 100-year time horizon (1988–2088) was used and reflected an assumption that in aggregate all discovered fields will continue to grow for the next 100 years. All fields discovered before 1950 were considered discovered in 1950 for the purpose of estimating inferred oil reserves. This assumption was made because technologies, higher prices, and development drilling patterns for older fields tended to affect most of the older fields in similar ways during the 1977–1988 period, regardless of the actual field discovery dates.

The EIA also developed estimates for oil recovery from EOR and included these as a subset of inferred crude oil reserves. Estimates of recovery from EOR projects were made by the Bartlesville Project Office (BPO) of the Office of Fossil Energy, Department of Energy (DOE). The estimates were based on EOR process models maintained by BPO and the Tertiary Oil Recovery Information System (TORIS) data base. The estimates for future incremental EOR production were based on the EIA reference case price path.

C American Association of Petroleum Geologists (1989 and 1992) and the Governor's Energy Council of Texas (1990)

Undiscovered Resources

In a study published in 1989, *Position Paper on the U.S Resource Base*, the American Association of Petroleum Geologists (AAPG) provided estimates for undiscovered resources under two price scenarios: a moderate price of less than $25/bbl in 1986 dollars, and a high price of $25–$50/bbl. The price scenarios were combined with an existing technology and efficiency scenario and an advanced technology and efficiency scenario (table A1-3). In 1990, the Governor's Energy Council of Texas reviewed and endorsed the AAPG estimates. In 1992, the AAPG prepared an updated oil resource assessment based on two price scenarios: $20/bbl and $27/bbl.

Reserve Growth

The AAPG's *Position Paper on the U.S. Resource Base* provided the first comprehensive estimate of reserve growth potential that took into account complete and up-to-date field production histories. Moderate and high price scenarios were used: less than $25/bbl in 1986 dollars and $25-50/bbl, respectively. The estimates for reserve growth reflected advanced oil recovery from existing resources through extended conventional and tertiary field development. The assessment was based on EOR estimates made by the National Petroleum Council (1984), those made by the Bartlesville Project Office (BPO) of the Department of Energy (DOE), and estimates for indicated and inferred reserves made by the Department of the Interior. In addition, the AAPG used the Bureau of Economic Geology's volumetric analyses of the 450 largest fields in Texas published in the *Atlas of Major Texas Oil Reservoirs* (Galloway and others, 1983).

D. National Research Council (1990)

Undiscovered Resources

ICF Resources Incorporated prepared a report, *U.S. Petroleum and Natural Gas Resources, Reserves and Extraction Costs*, for the National Research Council (Kuuskraa and others, 1990). In this study, the DOI estimates for undiscovered technically recoverable resources (U.S. Department of the Interior, 1989) were used and resource economics analysis was done to determine the replacement cost of undiscovered resources. The replacement cost was defined as the fully risked, levelized (over the life of a project) selling price for a barrel of oil that a project must receive to be economically viable. Economic viability was considered to be the full recovery of costs plus a 10-percent real return after taxes. The fully risked cost, determined over the productive life of the resource, included all investment and operating costs, and royalties and taxes. It also included outlays for geological and geophysical work, lease payments, and the drilling of successful and dry exploration wells.

The estimates were provided in two price scenarios in 1989 dollars ($24/bbl and $40/bbl) and two technology scenarios. In the implemented technology scenario (i.e., existing technology), it was assumed that conventional primary and secondary recovery practices would be used to recover the undiscovered resources in offshore reservoirs at water depths less than 400 m. In the advanced technology scenario, it was assumed that improvements in drilling efficiency would lower overall production costs and permit development of reserves in water depths greater than 400 m. It appears that both of the technology scenarios focused on offshore resource recovery. If it was assumed that technology would only enhance the recovery of offshore resources, this may explain why the estimates are low relative to the other studies.

Reserve Growth

The reserve growth estimates included inferred reserves, reserve growth, thermal EOR (heavy oil), immobile oil, and tar sands (table A1-4). The estimates were for economically recoverable oil in two price scenarios in 1989 dollars ($24/bbl and $40/bbl) and two technology scenarios (implemented technology and advanced technology).

E. Geoscience Institute for Oil and Gas Recovery Research (1989)

The Geoscience Institute for Oil and Gas Recovery Research, administered by The University of Texas at Austin, prepared a report on behalf of the Office of Fossil Energy of the Department of Energy (U.S. Department of Energy, 1989). The Geoscience Institute, a national consortium of leading universities and State research agencies with established advanced oil and gas recovery research capabilities, identified program needs and priorities required to

Table A1-3. United States oil resources estimates by AAPG (1989) (billion barrels*).

	Price less than $25/bbl		Price $25-$50/bbl	
	Technology & efficiency		Technology & efficiency	
	Existing	Advanced	Existing	Advanced
U.S. lower 48				
Proved reserves	20	20	20	20
Reserve growth mobile oil	10	45	14	65
Reserve growth tertiary (EOR)	6	15	36	80
Undiscovered	25	30	35	40
Subtotal	**61**	**110**	**105**	**205**
Alaska				
Proved reserves	7	7	7	7
Reserve growth	1	2	3	5
Undiscovered	8	10	25	30
Subtotal	**16**	**19**	**35**	**42**
Total	**77**	**129**	**140**	**247**

* As of December 1986. Prices in 1986 dollars.

Prepared by: Committee on the Resource Base, Division of Professional Affairs
American Association of Petroleum Geologists
Dr. William L. Fisher, Chairman

Sources: United States Geological Survey (Department of the Interior)
United States Minerals Management Service (Department of the Interior)
Bureau of Economic Geology (The University of Texas at Austin)
Bartlesville Project Office (Department of Energy)

Table A1-4. Reserve growth estimates (billion barrels).

	$24 bbl	$40 bbl
Existing technology		
Reserve growth	3.3	4.5
T.E.O.R.[a]	6.0	11.0
Immobile oil	4.6	9.1
Tar sands	0.8	2.1
Inferred	18.3	18.3
Total	**33.0**	**45.0**
Advanced technology		
Reserve growth	14.0	16.1
T.E.O.R.[a]	11.0	18.0
Immobile oil	6.2	14.6
Tar sands	0.8	3.1
Inferred	18.3	18.3
Total	**50.3**	**70.1**

Notes:

[a] Thermal enhanced oil recovery (heavy oil)

Source: Kuuskraa, V. A., McFall, K. S., and Godec, M. L., 1990, U.S. petroleum and natural gas resources, reserves and extraction costs: Fairfax, Va., ICF Resources, Inc., Report prepared for the National Research Council Committee on Production Technologies for Liquid Transportation Fuels, 83 p.

initiate an advanced geoscience oil and gas recovery research effort. As part of this work, the Geoscience Institute examined the advanced secondary and tertiary recovery potential of remaining oil resources in the United States.

The results of the Geoscience Institute's assessment were reviewed and endorsed by a panel of experts from industry, Federal agencies, State surveys, and universities. The Geoscience Institute estimates were based on the intermediate price level of $30/bbl and two technology scenarios (current implemented technology and advanced technology).

F. U.S. Department of Energy (1990)

The DOE developed a core research program whose goal was to maximize the economic producibility of the domestic oil resource. This research program was described in the report, *Oil*

Research Program Implementation Plan, published in April 1990. This plan was developed in support of the *Hydrocarbon Geoscience Research Strategy*, which was also released by the DOE in April 1990. An essential part of the research program was identification of targets for resource recovery in the near term (5 years or less); mid-term (10 years or less); and long term (beyond 10 years). The DOE provided estimates of additional reserves possible with well-designed research and development and technology transfer. The DOE estimates for potential reserves were based on the 1984 study of EOR by the NPC. Estimates for the extraction potential of the unrecovered mobile oil resource, using improved primary and secondary processes, were based on work done by the Bureau of Economic Geology at The University of Texas at Austin and ICF Resources Incorporated for the Bartlesville Project Office of the DOE.

G. Tertiary Oil Recovery Information System (TORIS)

In 1975, the National Petroleum Council (NPC) was requested by the Secretary of the Interior to perform a systematic study to estimate the potential of EOR in the United States (National Petroleum Council, 1976). The methodology used in the NPC study was based on screening a data base of 245 known reservoirs in California, Texas, and Louisiana to determine the most suitable EOR process to be applied. These reservoirs had remaining oil in place that represented 35 to 40 percent of that in known fields in the United States. Recovery estimates were based on prior field experience and the consensus of experts as to residual oil saturation, and displacement and sweep efficiencies. The costs associated with each recovery process were estimated, and the economics of each project were determined. The EOR potential for these reservoirs was then estimated using a number of crude oil price scenarios. EOR production for the nation as a whole was based on an extrapolation of these results. The extrapolation factors were based on the recovery process under consideration, estimates of original oil in place, and reservoir and crude oil properties.

In 1984, the NPC developed an expanded and improved reservoir data base and EOR model to analyze EOR potential in the lower 48 states. DOE data and information from proprietary sources were combined to create a data base on more than 2,500 reservoirs with original oil in place representing 66 percent of the U.S. oil resource base. The analytical system developed in this study evolved to become the Tertiary Oil Recovery Information System or TORIS. It contains engineering and geological information for more than 3,500 producing reservoirs, representing nearly 72 percent of total known oil discovered in the United States and detailed performance and economic models of advanced secondary and tertiary oil recovery processes. Unlike the 1976 study, no extrapolation of results was made to determine the full recovery potential for the entire domestic oil resource base.

PART II

Oil resource estimates from the studies reviewed here are summarized in tables A1-5 through A1-8. For general comparison purposes only, the results of the 1992 Oil Resources Panel are presented in these tables. Three members of the Oil Resources Panel presented various resource estimates for discussion when the Panel met on August 31 and September 1, 1992. These estimates are also reported in tables A1-5 through A1-8. Because these several studies utilized different assumptions of price and technology, the estimates summarized in these tables are only generally comparable.

Previous Estimates for Lower 48, Onshore—Undiscovered Resources

The DOI mean value estimates indicated that 41 percent of undiscovered recoverable crude oil resources exist onshore in the lower 48 states. The DOI estimates also indicated that 94 percent of the undiscovered fields in the lower 48 states consist of onshore small fields (i.e., fields with less than 1 MMbbl of oil equivalent). Of the undiscovered small oil fields, more than half (52 percent) were estimated to be commercial (U.S. Department of the Interior, 1989).

The EIA study of undiscovered resources suggested that advanced technology would not have a significant impact on increasing the recovery of undiscovered resources. The EIA assumed that the impact of advanced technology would be limited in terms of incremental recovery of onshore resources because current technology and practices were considered effective in achieving most of the possible recovery from these fields. For example, the conventional onshore estimate in the reference case

Table A1-5. Undiscovered resources—lower 48 states (billion barrels).

Previous estimates	Lower 48 states–onshore				Lower 48 states–offshore			
	Existing technology		Advanced technology		Existing technology		Advanced technology	
	Lower price	Higher price	Lower price	Higher price	Lower price	Higher price	Lower price	Higher price
Department of the Interior, 1989[a]	18.8	—	—	—	7.2	—	—	—
American Association of Petroleum Geologists, 1989	20.0	25.0	22.0	28.0	5.0	10.0	8.0	12.0
Governor's Energy Council of Texas, 1990	20.0	25.0	22.0	28.0	5.0	10.0	8.0	12.0
National Research Council, 1990	5.7	8.2	8.2	10.7	2.6	2.8	6.1	9.8
Energy Information Administration, 1990	19.4	—	20.7	—	8.4	—	14.5	—
Minerals Management Service, 1991	—	—	—	—	9.0	11.0	—	—
Average of previous estimates	**16.8**	**19.4**	**18.2**	**22.2**	**6.2**	**8.5**	**9.2**	**11.3**

Notes:

(a) DOI mean value estimate for undiscovered economically recoverable resources.

Table A1-5. Undiscovered resources–lower 48 states (billion barrels) (cont'd.).

Estimates presented at Oil Resources Panel, August 1992	Lower 48 states–onshore				Lower 48 states–offshore			
	Existing technology		Advanced technology		Existing technology		Advanced technology	
	Lower price	Higher price	Lower price	Higher price	Lower price	Higher price	Lower price	Higher price
I.C.F. Resources, 1992[b]	4.5	6.9	4.9	7.8	2.5	2.7	4.8	6.0
Gas Research Institute, 1992[c]	12.0	19.8	18.0	22.0	20.0	23.0	22.0	25.0
American Association of Petroleum Geologists, 1992[d]	39.0	64.0	60.0	100.0	6.2	10.3	10.0	16.5
Results of the Oil Resources Panel, August 1992								
Average of the Oil Resources Panel, 1992[e]	24	33	34	48	11	13	14	18

Notes:

(b) Unappreciated estimates. Presented to Oil Resources Panel by Jerry Brashear.

(c) Presented to Oil Resources Panel by Thomas Woods.

(d) Presented to Oil Resources Panel by Robert Gunn.

(e) The average of the estimates voted by the Oil Resources Panel members.

Table A1-6. Undiscovered resources—Alaska (billion barrels).

Previous Estimates	Alaska–onshore				Alaska–offshore			
	Existing technology		Advanced technology		Existing technology		Advanced technology	
	Lower price	Higher price	Lower price	Higher price	Lower price	Higher price	Lower price	Higher price
Department of the Interior, 1989[a]	7.9	—	—	—	0.9	—	—	—
American Association of Petroleum Geologists, 1989	7.0	14.0	9.0	16.0	1.0	11.0	1.0	14.0
Governor's Energy Council of Texas, 1990	7.0	14.0	9.0	16.0	1.0	11.0	1.0	14.0
National Research Council, 1990[b]	4.1	9.5	4.2	9.6	—	—	—	—
Energy Information Administration, 1990	7.9	—	13.2	—	0.8	—	3.4	—
Minerals Management Service, 1991	—	—	—	—	1.9	—	—	—
Average of previous estimates	**6.8**	**12.5**	**8.9**	**13.9**	**1.1**	**11.0**	**1.8**	**14.0**

Notes:

(a) DOI mean value estimate for undiscovered economically recoverable resources.

(b) The NRC estimates were not disaggregated into onshore and offshore resources.

Table A1-6. Undiscovered resources—Alaska (billion barrels) (cont'd).

Estimates presented at Oil Resources Panel, August 1992	Alaska–onshore				Alaska–offshore			
	Existing technology		Advanced technology		Existing technology		Advanced technology	
	Lower price	Higher price	Lower price	Higher price	Lower price	Higher price	Lower price	Higher price
I.C.F. Resources, 1992[c]	0	2.4	0	3.2	0	0.9	0	0.9
Gas Research Institute, 1992[d]	—	—	—	—	—	—	—	—
American Association of Petroleum Geologists, 1992[e]	9.9	14.0	15.8	22.4	5.6	7.9	—	12.6
Results of the Oil Resources Panel, August 1992								
Average of the Oil Resources Panel, 1992[f]	8	12	12	17	—	4	2	8

Notes:

(c) Presented to Oil Resources Panel by Jerry Brashear.

(d) Presented to Oil Resources Panel by Thomas Woods.

(e) Presented to Oil Resources Panel by Robert Gunn.

(f) The average of the estimates voted by the Oil Resources Panel members.

Table A1-7. Reserve growth—lower 48 states (billion barrels).

Previous Estimates	Lower 48 states–onshore				Lower 48 states–offshore			
	Existing technology		Advanced technology		Existing technology		Advanced technology	
	Lower price	Higher price	Lower price	Higher price	Lower price	Higher price	Lower price	Higher price
Department of the Interior, 1989	14.7	—	—	—	0.6	—	—	—
American Association of Petroleum Geologists, 1989	15.0	48.0	58.0	142.0	1.0	2.0	2.0	3.0
Geoscience Institute, 1989	—	—	—	92.0	—	—	—	—
Department of Energy, 1990	—	—	—	76.0	—	—	—	—
Governor's Energy Council of Texas, 1990	15.0	48.0	58.0	142.0	1.0	2.0	2.0	3.0
National Research Council, 1990	—	—	—	—	—	—	—	—
Energy Information Administration, 1990	30.5	—	47.6	—	2.3	—	3.4	—
Average of previous estimates	18.8	48.0	54.5	113	1.2	2.0	2.5	3.0

Table A1-7. Reserve growth—lower 48 states (billion barrels) (cont'd.).

Estimates presented at Oil Resources Panel, August 1992	Lower 48 states–onshore				Lower 48 states–offshore			
	Existing technology		Advanced technology		Existing technology		Advanced technology	
	Lower price	Higher price	Lower price	Higher price	Lower price	Higher price	Lower price	Higher price
I.C.F. Resources, 1992[a]	11.8	19.1	33.6	53.5	—	—	—	—
Gas Research Institute, 1992[b]	31.0	35.0	—	—	—	—	—	—
American Association of Petroleum Geologists, 1992[c]	—	—	—	80.0	—	—	—	—
Results of the Oil Resources Panel, August 1992								
Average of the Oil Resources Panel, 1992[f]	24	33	45	70	2	3	3	6

Notes:

(a) Presented to Oil Resources Panel by Jerry Brashear.

(b) Presented to Oil Resources Panel by Thomas Woods.

(c) Presented to Oil Resources Panel by Robert Gunn.

(d) The average of the estimates voted by the Oil Resources Panel members.

Table A1-8. Reserve growth—Alaska (billion barrels).

	Alaska–onshore and offshore			
	Existing technology		Advanced technology	
	Lower price	Higher price	Lower price	Higher price
Previous estimates				
Department of the Interior, 1989	6.4	—	—	—
American Association of of Petroleum Geologists, 1989	1.0	3.0	2.0	5.0
Governor's Energy Council of Texas, 1990	1.0	3.0	2.0	5.0
National Research Council, 1990	—	—	—	—
Energy Information Administration, 1990	6.4	—	6.4	—
Minerals Management Service, 1992	—	—	—	—
Average of previous estimates	**3.7**	**3.0**	**3.5**	**5.0**
Estimates presented at Oil Resources Panel, August 1992				
I.C.F. Resources, 1992	—	—	—	—
Gas Research Institute, 1992	—	—	—	—
American Association of Petroleum Geologists, 1992	—	—	—	—
Results of the Oil Resources Panel				
Oil Resources Panel, 1992[a]	5	7	7	13

Notes:

(a) The average of the estimates voted by the Oil Resources Panel members. These estimates are for onshore Alaska only. The Oil Resources Panel did not vote on estimates for offshore Alaska.

was 19.3 Bbbl and only 20.5 Bbbl in the advanced technology case (table A1-2).

Estimates of undiscovered resources in the lower 48 states, onshore, in a lower price scenario based on use of existing technology, ranged from 5.7 to 20.0 Bbbl, with an average estimate of 16.8 Bbbl. The estimates in a higher price scenario with existing technology ranged from 8.2 to 25.0 Bbbl, with an average of 19.4 Bbbl. The estimates in a lower price scenario with advanced technology ranged from 8.2 to 22.0 Bbbl, with an average of 18.2 Bbbl. The estimates in a higher price scenario with advanced technology ranged from 10.7 to 28.0 Bbbl, with an average of 22.2 Bbbl (table A1-5). A comparison of the average estimates suggests that technology results in an increase of between 8 and 14 percent in the recovery of undiscovered resources. Price results in an increase of between 16 and 22 percent in the recovery of undiscovered resources, so the impacts of price and technology are quite similar.

Previous Estimates for Lower 48, Offshore—Undiscovered Resources

One quarter of the estimated undiscovered recoverable crude oil resources in the United States is located in the Federal offshore of the lower 48 states (table A1-1). Advanced technology is expected to have a significant impact in increasing the recovery of undiscovered resources in the lower 48 states, offshore. The EIA estimates indicated that advanced technology would increase recovery by about 70 percent (table A1-2).

The estimates of undiscovered resources in the lower 48 states, offshore, in a lower price scenario with existing technology, ranged from 2.6 to 9.0 Bbbl, with an average of 6.2 Bbbl. In a higher price and existing technology scenario, the estimates ranged from 2.8 to 11.0 Bbbl, with an average of 8.5 Bbbl. In a lower price and advanced technology scenario, the estimates ranged from 6.1 to 14.5 Bbbl, with an average of 9.2 Bbbl. In a higher price and advanced technology scenario, the estimates ranged from 9.8 to 12.0 Bbbl, with an average of 11.3 Bbbl (table A1-5). These estimates suggest that advanced technology would increase recovery by 48 percent in a lower price setting and by 33 percent in a higher price setting. Price increases have a significant impact in the existing technology scenarios: price increases result in a 37-percent increase in recovery. This effect suggests that increased recovery of undiscovered resources can be achieved in two ways: an increase in oil prices and continued reliance on existing technology or, in the absence of increased prices, new investments in advanced technology.

Previous Estimates for Alaska, Onshore—Undiscovered Resources

Estimates for undiscovered resources in the Alaska onshore in a lower price and existing technology scenario ranged from 4.1 to 7.9 Bbbl, with an average of 6.8 Bbbl. In a higher price and existing technology scenario, the estimates ranged from 9.5 to 14.0 Bbbl, with an average of 12.5 Bbbl. The estimates in a lower price and advanced technology scenario ranged from 4.2 to 13.2 Bbbl, with an average of 8.9 Bbbl. In a higher price and advanced technology scenario, the estimates ranged from 9.6 to 16.0 Bbbl, with an average of 14.0 Bbbl (table A1-6).

Comparison of the average estimates suggests that price increases have a greater impact than improvements in technology in the recovery of undiscovered resources in onshore Alaska. For example, if only existing technology is used, increased oil prices would result in a 84-percent increase in recovery. In contrast, in a lower oil price setting, the use of advanced technology would increase recovery by 31 percent. It appears that a significant barrier to increased recovery of undiscovered resources in the Alaska onshore is the higher costs associated with resource exploration, drilling, and development in the Arctic region. It may also reflect the need for significant investment to build the infrastructure that would be required to facilitate expanded exploration and drilling activities in Alaska.

Previous Estimates for Alaska, Offshore—Undiscovered Resources

Alaska has approximately 20 percent of the undiscovered recoverable resources in the Federal offshore (table A1-1). In a lower price and existing technology scenario, the estimates ranged from 0.8 to 1.9 Bbbl, with an average of 1.1 Bbbl. In a lower price and advanced technology scenario, the estimates ranged from 1.0 to 3.4, with an average of 1.8 Bbbl.

A comparison of the average estimates suggests that price increases would significantly improve the recovery of undiscovered resources in Alaska offshore regions. This may reflect the higher costs associated with offshore development in Arctic environments and the need for considerable investment to build the infrastructure to facilitate increased exploration and drilling activity in the Alaskan offshore.

Previous Estimates for Lower 48, Onshore—Reserve Growth

The estimates for reserve growth in the lower 48 states, onshore, in a lower price and existing technology scenario, ranged from 14.7 to 30.5 Bbbl, with an average of 18.8 Bbbl. In a lower price and advanced technology scenario, the estimates ranged from 47.6 to 58.0 Bbbl, with an average of 54.5 Bbbl. In a higher price and advanced technology scenario, the estimates ranged from 76.0 to 142.0 Bbbl, with an average of 113.0 Bbbl (table A1-7).

A comparison of the average estimates suggests that technology has a greater impact than increased oil prices in improving reserve growth. For example, if existing technology continues to be used and higher oil prices are experienced, reserve growth would increase by approximately 155 percent. However, if lower oil prices prevail and advanced technology is used, reserve growth would increase an average of 190 percent.

Previous Estimates for Lower 48, Offshore—Reserve Growth

In a lower price and existing technology scenario, estimates of reserve growth for the lower 48 states ranged from 0.6 to 2.3 Bbbl, with an average of 1.2 Bbbl (table A1-7). A pattern similar to that observed in the reserve growth for the lower 48 states, onshore, is also found here. Technology appears to have a greater impact than price in increasing reserve growth, although the difference is not as great as that found in the case of reserve growth in the onshore. In the offshore, if existing technology continues to be used, higher oil prices would increase reserve growth by about 70 percent. If a lower price environment prevails, advanced technology would essentially double reserve growth.

Previous Estimates for Alaska, Onshore and Offshore—Reserve Growth

Estimates for reserve growth in Alaska in a lower price and existing technology scenario ranged from 1.0 to 6.4 Bbbl, with an average of 3.7 Bbbl. In a lower price and advanced technology scenario, estimates ranged from 2.0 to 6.4 Bbbl, with an average of 3.5 Bbbl (table A1-8). A comparison of the average estimates suggests reserve growth is the greatest when oil prices are higher and advanced technology is used.

APPENDIX 2. OIL RESOURCE POTENTIAL OF ALASKA

INTRODUCTION

Alaska has the greatest potential for the discovery of major new oil fields in the United States. Fields in Alaska that are considered "marginal" in an economic sense are thought to contain immense reserves in excess of those discovered in any onshore field in the lower 48 states during the past few decades. Remaining unexplored or underexplored areas in the Alaskan North Slope, both onshore and offshore, offer the best opportunities for oil discoveries in the giant and supergiant categories. The petroleum potential of onshore Alaska is concentrated in the North Slope region and is equally distributed between the coastal plain and foothills areas of the North Slope basin. Areas of interest in the Federal offshore include the Beaufort Sea, Chukchi Sea, Hope Basin, the Bering Sea, and the Gulf of Alaska (U.S. Department of Energy and State of Alaska, 1991).

Approximately 1.8 million barrels of oil per day (MMbbl/d) were produced in Alaska in January 1990, representing 25 percent of total U.S. oil production. Alaska has the largest oil field in North America, the Prudhoe Bay field. Prudhoe Bay produces 1.33 MMbbl/d and ranks first in production in the United States. Alaska also has the second largest producing field, Kuparuk River, which produces 0.30 MMbbl/d (U.S. Department of Energy and State of Alaska, 1991). With proved reserves of 6.5 billion barrels (Bbbl) as of December 31, 1990, Alaska has the second largest proved reserves in the country. In 1990, crude oil reserves were revised upward by 486 MMbbl mainly because of enhanced oil recovery (EOR) increases in the Prudhoe Bay and Kuparuk River fields and development drilling and waterflood operations in both fields (U.S. Department of Energy, 1991).

In Part I of the following discussion, various estimates of undiscovered resources are summarized and compared. In Part II, projections of future oil production in Alaska prepared by the U.S. Department of Energy and the State of Alaska are outlined.

PART I: ESTIMATES OF UNDISCOVERED RESOURCES

A. U.S. Department of the Interior (1989)

In a national assessment of the U.S. oil and natural gas resource base, the Department of the Interior (DOI) provided estimates of undiscovered conventionally recoverable oil resources located outside of known oil fields (U.S. Department of the Interior, 1989). The assessment did not include "unconventional" sources of oil such as tar deposits and intractable heavy oil deposits. This is significant given the considerable heavy oil deposits in the West Sak field. The estimates were based on a reference oil price of $18 per barrel for January 1, 1987. Although exploration costs were not included, transportation and pipeline development costs were included in the calculation of resource estimates for Alaska.

One-third (i.e., 34 percent) of the undiscovered recoverable oil resources in the United States were estimated to be located in Alaska. Undiscovered recoverable resources in Alaska were estimated to be 16.6 Bbbl (mean value). Of that total, 13.2 Bbbl was estimated to be in areas onshore and in State waters, and 3.4 Bbbl was estimated to be in the Federal offshore. These estimates were for technically recoverable resources. When the economics of resource development were taken into consideration, the estimates decreased significantly, reflecting the high costs of development in frontier areas. The undiscovered economically recoverable resources were estimated to be 8.8 Bbbl (mean value), or approximately one-half of the technically recoverable resources. Of the economically recoverable resources, 7.9 Bbbl was estimated to be located in areas onshore and in State waters, and 0.9 Bbbl in the Federal offshore. In 1990, the Minerals Management Service of the DOI revised the estimate for the Alaskan Federal offshore. The estimate was revised upward from 0.9 to 1.87 Bbbl.

B. American Association of Petroleum Geologists (1989 and 1992) and the Governor's Energy Council of Texas (1990)

In a moderate price scenario of less than $25/bbl in 1986 dollars, with existing technology and efficiency, undiscovered resources in Alaska were estimated to be 8.0 Bbbl. With advanced technology and efficiency, this increased to 10.0 Bbbl (American Association of Petroleum Geologists, 1989). These estimates are comparable to the DOI mean value estimate of 8.8 Bbbl for undiscovered economically recoverable resources. In a high price scenario of $25–50/bbl (1986 dollars) with existing technology and efficiency, undiscovered resources were estimated to be 25 Bbbl. With advanced technology and efficiency, this increased to 30 Bbbl. The AAPG estimates were reviewed and endorsed in 1990 by the Governor's Energy Council of Texas (table A2-1).

In 1992, the AAPG estimated undiscovered technically recoverable conventional resources in Alaska to be 25.75 Bbbl (mean estimate). In a $20/bbl (1992 dollars) scenario with existing technology, Alaska oil resources were estimated to be 15.5 Bbbl: 9.9 Bbbl onshore and 5.6 Bbbl offshore. In a $27/bbl (1992 dollars) scenario with existing technology, the estimate increased to 21.9 Bbbl: 14.0 Bbbl onshore and 7.9 Bbbl offshore (table A2-1).

C. Energy Information Administration (1990)

The Energy Information Administration (EIA) examined the impact on resource recovery of access restrictions and technology. Estimates were presented in four scenarios: reference, access, advanced technology, and advanced technology and access. The reference case was considered as a subset of an overall recoverable target, from which certain portions were deducted because of access restrictions or limitations on technology. The access case allowed for exploitation of all areas but with only existing technology. The advanced technology case was based on an assumption of substantial technological development with continuation of restrictions on access in selected areas. The combined access and advanced technology case included the gains from both access to all areas of the United States and advances in technology. In all four scenarios, the results were for undiscovered economically recoverable resources and were based on a 40-year time horizon (1990–2030).

The EIA study incorporated mean value estimates from the 1989 DOI report and the associated economic assumptions, including a reference oil price of $18/bbl for January 1, 1987 in constant 1987 dollars. The EIA study also incorporated from the DOI report the assumption that exploratory drilling of each play or prospect had been completed and that the decision about whether the resulting discovery was economically recoverable was made on January 1, 1987, on the basis of development and production costs of that date.

The EIA assumed that during the next decade, the bulk of Alaskan oil production would be from known fields: Prudhoe Bay, Kuparak River, Endicott, Lisburne, West Sak, and Milne Point. It was also assumed that fields on the Alaskan North Slope that will yield commercial production must be large. For the onshore resource estimates, the EIA used an initial discovery size, from which subsequent discoveries decline until the resource base is depleted. The EIA assumed that the initial and second discovery sizes in the access case were 1,000 and 750 MMbbl recoverable oil, respectively. It was assumed that in the absence of any large discoveries, South Alaska oil production would decline steadily at 10 percent per year until reaching a level of 0.02 MMbbl/d.

The EIA estimates of ultimate recoverable reserves for Alaska onshore, in billion barrels, were as follows: reference case, 5.02; access, 7.90; advanced technology, 8.39; access and advanced technology, 13.20. The EIA estimate in the access and advanced technology case is the same as the mean value for undiscovered recoverable resources for Alaska onshore and State waters in the 1989 DOI study.

In the estimates for offshore Alaska, the EIA did not distinguish between the reference and access cases because there are no access restrictions that might limit recovery from the recoverable oil resources in the offshore areas. The EIA estimated recovery from the Beaufort Sea to be 0.20 Bbbl in the reference and access case, increasing to 1.25 Bbbl in the advanced technology case. Recovery from the Chukchi Sea was estimated to be 0.60 Bbbl in the reference and access case, increasing to 1.95 Bbbl in the advanced technology case. An additional 0.2 Bbbl of undesignated oil recovery was included

Table A2-1. Comparison of the estimates of Alaska undiscovered oil resources (billion barrels).

Scenarios	DOI 1989	EIA 1990	AAPG[c] 1989	AAPG[d] 1992	NRC[e] 1990	GEC[c] 1990
Lower price with existing technology	8.8[a]	—	8.0	15.5	4.1	8.0
Lower price with advanced technology	—	16.6[b]	10.0	15.8	4.2	10.0
Higher price with existing technology	—	—	25.0	21.9	9.5	25.0
Higher price with advanced technology	—	—	30.0	35.0	9.6	30.0

Notes:

(a) Mean value for undiscovered economically recoverable resources. The mean value for undiscovered recoverable resources is 16.6 Bbbl. Both estimates are based on a reference oil price of $18/bbl as of January 1, 1987.

(b) Assumes advanced technology, no access restrictions, and a reference oil price of $18/bbl as of January 1, 1987.

(c) Lower price is less than $25/bbl (1986 dollars). Higher price is $25-50/bbl (1986 dollars).

(d) Lower price assumption is $20/bbl (1992 dollars). Higher price assumption is $27/bbl (1992 dollars).

(e) Lower price assumption is $24/bbl (1989 dollars). Higher price assumption is $40/bbl (1989 dollars).

in the advanced technology case. The Beaufort Sea and Chukchi Sea estimates, together with the 0.2 Bbbl of undesignated oil recovery in the advanced technology case, constitute 3.4 Bbbl, which is the same as the mean value estimate of 3.4 Bbbl for undiscovered recoverable resources for the Alaskan Federal offshore in the 1989 DOI study.

D. National Research Council (1990)

ICF Resources Incorporated prepared a report, *U.S. Petroleum and Natural Gas Resources, Reserves and Extraction Costs*, for the National Research Council (Kuuskraa and others, 1990). This study endorsed the estimates for undiscovered recoverable resources from the 1989 DOI report. Thus, undiscovered technically recoverable resources in Alaska were estimated to be 16.6 Bbbl. The economic recovery of undiscovered resources was examined in two technology scenarios. The implemented technology scenario assumed that conventional primary and secondary recovery practices would be used to recover undiscovered resources in offshore reservoirs at water depths less than 400 m. In the advanced technology scenario, it was assumed that improvements in drilling efficiency would lower overall production costs and permit development of reserves in water depths greater than 400 m. Thus, it appears that the study focused on recovery of undiscovered resources in offshore areas only. This may explain why the estimates are low relative to other estimates (table A2-1).

In a moderate price scenario ($24/bbl) with implemented technology, undiscovered economically recoverable oil was estimated to be 4.1 Bbbl. With advanced technology, this increased slightly to 4.2 Bbbl. This is somewhat comparable to the EIA estimate of 3.2 Bbbl in the advanced technology case for the Beaufort Sea and Chukchi Sea. In a high price scenario ($40/bbl) with implemented technology, undiscovered economically recoverable oil was estimated to be 9.5 Bbbl. With advanced technology, this increased slightly to 9.6 Bbbl. Thus, the estimates prepared for the NRC indicated that advanced technology has limited impact in increasing recovery of undiscovered resources.

PART II: ALASKAN OIL PRODUCTION PROJECTIONS—DEPARTMENT OF ENERGY AND THE STATE OF ALASKA (1991)

Introduction

In January 1991, the Department of Energy published a report, *Alaska Oil and Gas: Energy Wealth or Vanishing Opportunity?*, based on a joint study with the State of Alaska. The report provided a summary of previous studies of Alaskan oil and gas resources. In addition, the report provided an analysis of producing fields, known nonproducing fields, and undiscovered resources to determine remaining recoverable oil, economically recoverable reserves, and minimum economic field sizes (MEFS) for undiscovered resources. Development costs, operating costs, transportation costs, State and Federal taxes, and royalties were analyzed for producing fields and derived for known undeveloped fields and undiscovered resources. An economics model was used to determine the MEFS for the Arctic National Wildlife Refuge (ANWR), the Chukchi Sea, the Beaufort Sea, and the National Petroleum Reserve—Alaska (NPRA).

Production Forecasts

The developed fields in the North Slope area include the Prudhoe Bay field, the Lisburne Participating Area, which is part of the Prudhoe Bay field, the Kuparuk River field, the Endicott field, and the Milne Point field. The Niakuk and Point McIntyre reservoirs were also included in the study because planning was considered to be sufficiently advanced to allow development within the next 3 to 4 years. Production forecasts were developed for three scenarios: a reference case, a most likely case, and a high case. The reference case included only in-place projects. The most likely case and high case both included planned and potential projects (table A2-2). Production forecasts published by the Alaska Department of Natural Resources were used for currently producing fields. These forecasts may have included oil volumes that cannot be economically recovered. They did not include potential increases from expansions of recovery programs without performance history, from approved new recovery programs not yet installed,

Table A2-2. Alaskan oil production forecast—projected recoverable oil as of January 1, 1990 (million barrels).

Field	Reference case	Most likely case	High case (advanced oil recovery technology)
Prudhoe Bay	4,902	6,307	6,984
Kuparuk River	935	1,514	1,666
Duck Island (Endicott)	283	311	342
Lisburne	156	159	191
Milne Point	55	55	60
Niakuk	–	58	63
Point McIntyre	–	300	330
Total	**6,331**	**8,704**	**9,636**

Notes:

1. Source: U.S. Department of Energy, in cooperation with the state of Alaska, 1991, *Alaska oil and gas: energy wealth or vanishing opportunity?*: DOE/ID/01570-H1, 274 p.
2. Recoverable oil is the volume of oil that can be recovered if production operations are continued without consideration of an economic limit.
3. Reference case only includes in-place projects.
4. Most likely case and high case include planned and potential projects.

or from future programs in the long-range plans of the operators.

In the reference case, which assumed no new investments, the projected recoverable oil was estimated to be 6.3 Bbbl (table A2-2). The increase in projected recovery, which can be expected as a result of future investments and project expansions, was determined for each field for the most likely case. Of the discovered but undeveloped accumulations, the Point McIntyre and Niakuk fields were included in the most likely case. The impact of EOR was considered in the most likely case for specific fields (i.e., Prudhoe Bay, Kuparuk River, Milne Point, and Duck Island / Endicott). The impact of completion of development drilling, new equipment, well-workover programs, infill drilling, and improved performance was also taken into consideration in the most likely case. The projected recoverable oil in the most likely case was 8.7 Bbbl.

The production forecast in the high case was based on advanced oil recovery techniques. Currently, one or more secondary recovery techniques are being used at all of the active fields on the North Slope. Further enhancement of recovery might result from the use of: miscible CO_2 flooding, nonmiscible CO_2 flooding, foam to improve WAG processes (where water and enriched gas are alternately injected), surfactant flooding, polymer flooding, alkaline flooding, steam injection, hot-water injection, hot-gas cycling, and in situ

combustion. It was assumed that economic application of any of these EOR processes after the completion of waterflooding is unlikely because of the large volumes of water that would have to be produced before any increased oil recovery could be achieved. Therefore, recovery in the high case was expected to come from the early application of an EOR process or improved effectiveness of some process already being employed.

With the exception of the Prudhoe Bay field, it was assumed that ultimate recovery would increase by about 10 percent above the estimates in the most likely case. The potential recovery for the Prudhoe Bay field was assumed to be only 5 percent because the field is partly developed for enriched miscible gas recovery (table A2-2). For these higher recoveries to be realized, significant improvements in existing EOR technology or new EOR technology would be required. No additional investments for facilities or wells were assumed, but operating costs were increased in the high case.

In the calculation of economically recoverable oil, the analysis took into consideration development costs by field, future investments, drilling and completion costs, operating costs by field, Alaskan and Federal taxes and royalties, transportation costs (i.e., shipping costs and pipeline tariffs), and oil prices. The results of the calculation of economically recoverable resources are presented in table A2-3.

Oil Potential of Undeveloped Fields

The following known undeveloped fields were assessed: Gwydyr Bay Unit, Seal Island / North Star, Sandpiper, and West Sak (table A2-4). These were the fields thought to have sufficient reserves potential to be considered for development. The West Sak field is a shallow, low-temperature, heavy oil reservoir, much of which is contained in the Kuparak River Unit area. Estimates of the resource in place are as high as 20 Bbbl. The operator of the West Sak field thinks that hot waterflooding is a viable recovery mechanism. Potential recoverable oil was estimated at 423 MMbbl. The Seal Island / North Star accumulation is 6 mi offshore and about 12 mi northwest of Prudhoe Bay. Recoverable oil was estimated to be between 150 and 300 MMbbl. Because the reservoir data for this field were not available for review at the time of the study, the lower reserve estimate was used. The Sandpiper Island accumulation, on Federal offshore leases, appeared to be similar to the Seal Island / North Star areas (i.e., both have been indicated to have a Sadlerochit pay zone). Therefore, the Sandpiper Island accumulation was assumed to contain 150 MMbbl of recoverable oil. The calculation of economically recoverable oil for these four fields was based on production forecasts, development costs, operating costs, pipeline tariffs, taxes, and royalties (U.S. Department of Energy and State of Alaska, 1991).

Summary of Results

The results of the study indicated that production from North Slope fields will decrease from 1.8 MMbbl/d in January 1990 to 1.0 MMbbl/d in 2000. Development of known undeveloped fields and application of advanced recovery techniques to existing fields and potential developments on the North Slope will only slow this decline. It was concluded that discovery of another field similar in size to Prudhoe Bay or the combination of several large discoveries is necessary to stop or to reverse the decline in oil production (U.S. Department of Energy and State of Alaska, 1991).

Table A2-3. Alaskan oil production forecast—projected recoverable oil and economically recoverable reserves as of January 1, 1990 (million barrels).

Field	Low recovery case		Most likely case		High reserves case	
	Recoverable	Economically recoverable	Recoverable	Economically recoverable	Recoverable	Economically recoverable
Prudhoe Bay	4,902	4,859	6,307	6,266	6,984	6,862
Kuparuk River	935	935	1,514	1,514	1,666	1,666
Duck Island (Endicott)	283	279	311	311	342	342
Lisburne	156	154	159	157	191	191
Milne Point	55	53	55	53	60	57
Niakuk	–	–	58	57	63	63
Point McIntyre	–	–	300	298	330	327
Total	**6,331**	**6,280**	**8,704**	**8,656**	**9,636**	**9,508**

Notes:

1. Source: U.S. Department of Energy, in cooperation with the state of Alaska, 1991, *Alaska oil and gas: energy wealth or vanishing opportunity?*: DOE/ID/01570-H1, 274 p.
2. Point McIntyre and Niakuk production estimated to start in 1993.
3. "Reserves" in this study are defined as the economically recoverable oil volumes.

Table A2-4. Alaskan oil production forecast—projected recoverable oil and economically recoverable reserves for known undeveloped fields as of January 1, 1990 (million barrels).

Field	Recoverable	Economically recoverable
Gwydyr Bay Unit	60	58
Seal Island/North Star	150	145
Sandpiper	150	147
West Sak	423	385
Total	**783**	**735**

Source: U.S. Department of Energy, in cooperation with the state of Alaska, 1991, *Alaska oil and gas: energy wealth or vanishing opportunity?*: DOE/ID/01570-H1, 274 p.

APPENDIX 3. ESTIMATES OF UNDISCOVERED RESOURCES, OUTER CONTINENTAL SHELF

INTRODUCTION

In 1990, the Outer Continental Shelf (OCS) Federal offshore ranked fourth in the United States with respect to crude oil reserves. With reserves of 2.8 billion barrels (Bbbl), the OCS constituted 11.0 percent of the total reserves in the United States. More than two-thirds of the crude reserves are off the coast of Louisiana. The magnitude of these reserves has been relatively constant over the last 5 years (U.S. Department of Energy, 1991). It has been estimated that one-third of the undiscovered recoverable crude oil resources occur in the Federal offshore (U.S. Department of the Interior, 1989).

UNDISCOVERED RESOURCES

In 1989, the Department of the Interior (DOI) published a national resource assessment, *Estimates of Undiscovered Conventional Oil and Gas Resources in the United States—A Part of the Nation's Energy Endowment*. This report included estimates of undiscovered resources for the OCS prepared by the Minerals Management Service (MMS) of the DOI. The MMS used data received from industry exploration and development programs performed under permits or mineral leases issued for the OCS. The MMS developed estimates of undiscovered economically recoverable oil by using the Probabilistic Resource Estimates—Offshore (PRESTO) model. This model performed multiple simulations of industry exploratory drilling efforts for potential prospects and ranked possible outcomes of such efforts, which prove economically successful in terms of resources "discovered" and probabilities of occurrence (U.S. Department of the Interior, 1989).

For the estimates of undiscovered recoverable resources, the MMS used statistical techniques to extrapolate the size and number of all potential fields within the areas being modeled. The MMS defined this category of resources to include potential fields of 1 million barrels of oil equivalent (MMBOE) or larger. In Alaska, the MMS excluded prospects that were smaller than one-half a leasing block from the recoverable resource estimates. These implicit economic assumptions resulted in lower recoverable resource estimates. When explicit economic criteria were then applied to the recoverable resource volumes to calculate the economically recoverable volumes, the result may have been unintended double discounting and a reduction of the economically recoverable resource estimates (National Research Council, 1991). Thus, the estimates for the Federal offshore resources in the DOI study can be considered conservative.

For the total Federal offshore, only one-half of the recoverable resources were considered to be economically recoverable (table A3-1). In all four offshore areas, the economically recoverable resource estimates were significantly lower than the recoverable resource estimates. This reflected the higher development costs and technological constraints associated with offshore areas, particularly in Alaska. These results also indicated that the expected major discoveries were not forthcoming in the frontier exploration areas of Alaska and the Atlantic offshore. Most, 85 percent, of the undiscovered economically recoverable resources were expected from the Pacific Coast and the Gulf of Mexico, 11 percent from Alaska, and the remaining portion from the Atlantic coast.

The estimates of undiscovered economically recoverable oil were revised as of January 1990 (U.S. Department of the Interior, 1991). It was determined that the economic assumptions used in the 1989 DOI report remained valid; therefore, these assumptions were retained in the 1991 revision. Undiscovered economically recoverable estimates for the entire Federal offshore were increased from 8.2 to 10.94 Bbbl. The estimates for the Alaska offshore were increased from 0.9 to 1.87 Bbbl. The estimates for the Pacific Coast offshore were increased from 2.0 to 2.49 Bbbl. The estimates for the Gulf of Mexico were increased from 5.0 to 6.34 Bbbl. Finally, the estimates for the Atlantic Coast offshore were increased from 0.2 to 0.25 Bbbl (table A3-1).

The reasons for the upward revision of estimates differed in each region. In the Alaska offshore region, the estimates for the Chukchi Sea more than doubled: the mean case for risked oil increased from 0.59 to 1.36 Bbbl. The estimates for the Beaufort Sea

Table A3-1. A comparison of MMS estimates of oil resources for the federal offshore (billion barrels).

	Undiscovered recoverable oil (mean value)	Undiscovered economically recoverable oil (mean value)	
Assessment Year	1987[a]	1987[a]	1990[b]
Alaska Offshore	3.4	0.9	1.87
Pacific Coast Offshore	3.4	2.0	2.49
Gulf of Mexico	8.6	5.0	6.34
Atlantic Coast Offshore	0.7	0.2	0.25
Total Federal Offshore [c]	**16.1**	**8.2**	**10.94**

Notes:

(a) U.S. Department of the Interior, 1989, *Estimates of undiscovered conventional oil and gas resources in the United States—a part of the Nation's energy endowment*, 44 p.

(b) U.S. Department of the Interior, 1991, *Estimates of undiscovered economically recoverable oil & gas resources*: OCS Report, MMS 91-0051, 30 p. (Primary case economic scenario).

(c) Mean value totals may not be equal to the sums of the constituent means because numbers have been independently rounded.

were also revised upward from 0.21 to 0.38 Bbbl. In the Gulf of Mexico, there was a dramatic increase in estimates for the Eastern Gulf of Mexico: the estimate more than tripled, increasing from 0.22 to 0.95 Bbbl. In the Pacific Coast offshore region, the estimates for Northern California doubled, increasing from 0.34 to 0.69 Bbbl. Changes to the Point Arena Basin accounted for most of the increase.

The MMS concluded that of all the U.S. frontier exploration areas, the Chukchi Sea has the greatest potential in terms of the possible magnitude of undiscovered resources. The area contains many large, undrilled structures, and industry interest in the area is high. A major concern for this area is the high costs associated with exploration and development. The estimates of economically recoverable resources in the Arctic were highly dependent on prevailing and projected economic conditions (U.S. Department of the Interior, 1989). The Hope Basin was adversely affected by the small number of prospects and high economic costs. There was a large increase in estimates of undiscovered resources in the Eastern Gulf of Mexico. This area included a large number of prospects. The Eastern Gulf of Mexico was considered by the MMS to have the greatest potential in terms of the probability of a commercial discovery. There was also an improved resource outlook for Northern California, particularly in the Point Arena Basin (U.S. Department of the Interior, 1991).